Rajeev Pratap Singh • Abhijit Sarkar
Editors

Waste Management

Challenges, Threats and Opportunities

Waste and
Waste Management

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RAJEEV PRATAP SINGH
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NOTICE TO THE READER

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PREFACE

Over the last couple of decades, rapid urbanization, unplanned industrialization, and rising population jointly created several issues worldwide, particularly in developing and underdeveloped countries. One such issue that requires urgent attention is the ever-increasing waste problem which has become exasperation for regional and local governments and an issue of both national and international importance. Waste in any form and character are the byproduct of anthropogenic activities. To move forward towards a cleaner and greener future, we need to deduce sustainable technologies- to reduce, reuse and recycle our waste. This book brings important information and views on new developments of waste management technologies, especially from developing and underdeveloped countries. In this volume there are contributions of experts from different countries. Each one of them shows interesting research outputs on waste management technologies which are both economical and eco-friendly; and if applied properly, then can lead us towards a '*zero-waste*' world.

Chapter 1 - Developing countries are saddled with widespread pollution from poorly managed organic waste due to several factors including technical, budgetary and infrastructural deficits to manage these wastes. Yet, the waste burden in these countries is anticipated to double by the next decade, if nothing appreciable is done. The implication for public health and the environment is enormous as poor waste management practices may cause an outbreak of communicable diseases, pollute surface and ground waters, and cause flooding and other environmental problems. The organic fraction of the waste stream in Ghana is huge and this offers the greatest opportunity to recycle products such as compost and biochar that can be used for horticultural and landscaping purposes to generate some revenue to manage these facilities. This chapter reviews the dynamics of solid wastes generation, and its management in Ghana, and analyzes the opportunities, challenges and threats of managing organic wastes and other fractions, from policy, technological and institutional perspectives. The lessons drawn are of importance to other developing countries in Sub-Saharan Africa.

Chapter 2 - Enzyme operations fit into the traditional two chemical and biological treatment systems because they involve chemical reactions founded on the actions of the organic catalysts. Various enzymes from plants and micro-organisms have been reported to play significant roles in many waste applications. Before the full potential of enzymes can be achieved, a few significant issues remain to be solved (settled). These include: the development of enzyme sources in amounts that are necessary for industrial scale at a low cost; the demonstration of the feasibility (possibility) of enzymes under conditions encountered in the sewage efficient treatment; the wastewater characterization of the reaction products and assessment of their impact on downstream processes or on the environment within they are released and finally the identification approaches for solid residues evacuation, among others.

Chapter 3 - Technology has undoubtedly provided copious advantages, but simultaneously has also generated large quantities of waste which is discarded in the name of garbage. Not only industrial waste but even domestic waste is today just disposed and not handled. Most cities do not even have landfills as they just fill up the land. The per capita generation of solid waste for urban areas is about 0.55 kg/person per day and about 0.4 - 0.45 kg/per person per day for people living in rural areas (these values may vary depending on different types of survey activities). Most of the waste generally is dumped and burnt. The "NIMBY" (Not In My Back Yard) process is often prevalent. In India an active "group" of people try their best to salvage what they can for recycling from the dump sites. As waste is not segregated, most of the material that is salvaged from the dump site has already lost its quality. Today the world is moving towards Zero Waste Management. There are cases where countries are starting to adopt Zero Waste Goals as policy measures. The best way to handle the 80% of organics generated at the household level is to compost it. Composting is a controlled oxidative process that involves a heterogeneous organic substrate in the solid state, evolved by passing through a thermophilic phase leading to the production of CO_2, water, minerals and stabilized organic matter called compost.

Chapter 4 - Agricultural wastes are among the causes of environmental pollution which also shorten the fallow period, which reduces the time for aerobic degradation of the crop residue. The common practice to overcome the accumulation of undecomposed crop residue is open burning of straw and stubbles which has been also used traditionally to sanitize agricultural fields against pests and diseases. Due to environmental concerns, thermal straw management is now being reconsidered in many regions of the world and has been widely banned in China and India. Biological degradation, for both economic and ecological reasons, has become an increasingly popular alternative for the treatment of agricultural, industrial, organic as well as toxic waste. Agriculture wastes recycling can bring tremendous benefits to agriculture and land management in long run. In addition there are the benefits of a cleaner environment, a healthier habitat and an intelligent use of all available recyclable resources without condemning them as wastes.

Chapter 5 - In the context of freshwater scarcity, technological intervention is essentially required for recycling of wastewater, though a formulation of well planned strategies. Sewage fed aquaculture is one such strategy established to be a reliable system with proven techniques by which used water is reused. In this system, sewage is treated by the technique known as 'Bio-remediation' through application of macrophyes. This is a unique method through which a suitable amount of nutrients is recovered from sewage water and then utilized under controlled manner with the purpose of fish production through fertilization of pond water. The nutrient load contained in raw sewage water could, otherwise, be wasted. That 1.0 L of sewage water is utilized to estimate of producing 0.309 g of fish biomass through nutrient recovery as much as 0.05 g in form of N and P is an effective procedure, apart from 0.99 L of water restoration. Utilization of such bio-remedied water requires specific technology in promoting fish culture, including pond preparation, species selection, maintenance of species ratio, stocking density, farming method and harvest. In India, intervention of proper technological support revealed the fish production achieved up to 5250 kg ha^{-1} yr^{-1}, which has been better yield than that in feed based culture practice. However, fish reared in a sewage fed system is a concern to many with regard to its safe consumption because of the contaminant load contained in sewage water. The amount of contaminants that cause aquatic pollution can be reduced through 'Biological treatment' to the extent by which it is to be suitable for its use in aquaculture systems. Besides, the traverse of the long distance of raw sewage from its origin to culture ponds via stabilized pond leads to reduce the amount of contaminants, including heavy metals and microbial load. Also, sewage concentration made less than 50% becomes weakened to be the least toxic or to have no toxic effect on organisms and in turn be suitable for fish rearing. In the context of global warming, using sewage water through technological intervention is a unique approach which needs to be encouraged.

Chapter 6 - Solid waste management in cities is an integral part of urban and environment management. Municipal solid waste management, like most of other infrastructural services has come under great stress. In the low priority areas, solid waste management was never taken up seriously by public, concerned agencies or authorities but now the piled up waste is threatening our health and environment. The waste management technology is capable of maintaining both environmental and energy concerns because it has dual benefits of pollution control as well as energy production. Waste incineration is defined as the combustion of solid and liquid waste in controlled combustion facilities. It is one of the waste treatment processes that involve the combustion of organic substances contained in waste materials. Incineration converts the waste into ash, flue gas and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned before they are dispersed into the atmosphere. The heat generated by incineration can be used to generate electric power.

Chapter 7 - Most of the cities in India show inefficiencies in environmentally sound and sustainable waste management. An audit on the performance of waste management undertaken by the Comptroller and Auditor General (CAG) of India in 2007 revealed that there are no states that have completed comprehensive data about waste volumes and composition. As stated, priority of reducing, recycling and reusing waste have been largely ignored while municipalities focus instead on disposal. The formal waste management system in most of the cities is started from households and ends up in landfills where all type of waste (mixed household, commercial, institutional etc.) either has been collected from door to door by waste collector from municipality or thrown away into designated dustbin by the households. From there the waste is collected by municipality persons and dumped into the landfill. Besides formal management, informal management system is usual scenario for thriving of informal recycling economy in large cities in India.

Chapter 8 - Solid waste disposal and management is a challenge for scientists, municipalities and governmental agencies all over the world. Various solid waste management methods are available but all methods have their own benefits and limitations. So scientists are continuously working for the development of ecologically sustainable and economically cheaper strategies. In yesteryears several new biological approaches for solid waste management have been developed including biomethanation, bioremediation, microbial enzyme solutions, vermicomposting, composting etc. In this chapter, a review of vermicomposting process, different process variables, suitable earthworm species, effective waste management and potential application of the product to the plants is presented.

Chapter 9 - Rapid increase in population has led to increased demand for food and shelter, putting immense pressure on various natural resources for their needs. Consequently, it has been producing huge amounts of solid waste materials. This is one of the major global challenges for us in the present. The substantial increase in demand for oil and fats in the global market has led to rapid growth of palm oil industry in South East Asian countries like Indonesia and Malaysia. In Malaysia, palm oil mill waste contributes the highest fraction of total industrial solid wastes. Although there are many issues and challenges associated with palm oil industry like environmental pollution, deforestation, biodiversity loss, and social conflicts etc., it also provides various opportunities in terms of products obtained from palm oil mill waste. Keep in mind the present situation and the current chapter was planned with the objective to overlook the issues, opportunities and challenges associated with palm oil industry/oil palm waste in South East Asia with major emphasis on Malaysia.

Chapter 10 - A revolution is unfolding in studies about earthworms (Sir Charles Darwin's 'unheralded soldiers of mankind') for biological recycling of all human wastes (solid wastes and wastewater) and using the recycled products and resources generated (vermicompost, treated nutritive water & earthworms biomass) to promote sustainable agriculture (organic farming) without agro-chemicals. The conventional methods of solid waste management by disposal in 'engineered landfills', wastewater treatment by treatment plants with sludge generation (biohazard) and their disposal in secured landfills are all highly expensive and also affect the environment by emitting huge pollutants and greenhouse gases inducing global warming. Construction of engineered landfills incurs 20-25 million US dollars upfront before the first load of waste is dumped. Landfill emits toxic trace gases like 'xylene', 'toluene' and powerful greenhouse gases like methane (CH_4) and nitrous oxides (N_2O). STPs also emit CH_4 and N_2O. Molecule to molecule methane is 22 times and nitrous oxides is 312 times more powerful than carbon dioxide. In 2005, landfill disposal of MSW contributed 17 million tons CO_2-e (equivalent) of GHG in Australia, equivalent to the emissions from 4 million cars or 2.6% of the national GHG emissions.

Chapter 11 - The modern age is considered as the 'digital age'; and it is constantly generating wastages; especially the electronic waste (e-waste). The e-waste is a matter of concern and the problem is worldwide. The more we are technologically advanced; there will be more and more e-waste generation. The problem related to e-waste lies in its properties and nature, because these are sometimes silent killers. There are some crucial issues related to e-waste generation and management and of course related to handling. E-waste export remains a dirty little secret of the high-tech revolution.

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Chapter 1

RECYCLING OF AGRICULTURAL AND MUNICIPAL SOLID WASTES IN GHANA: CHALLENGES, THREATS AND OPPORTUNITIES

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ABSTRACT

Developing countries are saddled with widespread pollution from poorly managed organic waste due to several factors including technical, budgetary and infrastructural deficit to manage these wastes. Yet, the waste burden in these countries is anticipated to double by the next decade, if nothing appreciable is done. The implication for public health and the environment is enormous as poor waste management practices may cause an outbreak of communicable diseases, pollute surface and ground waters, and cause flooding and other environmental problems. The organic fraction of the waste stream in Ghana is huge and this offers the greatest opportunity to recycle to products such as compost and biochar that can be used for horticultural and landscaping purposes to generate some revenue to manage these facilities. This chapter reviewed the dynamics of solid wastes generation, and its management in Ghana, and analyzed the opportunities, challenges and threats of managing organic wastes and other fractions, from policy, technological and institutional perspectives. The lessons drawn are of importance to other developing countries in Sub-Saharan Africa.

Keywords: Agricultural waste, municipal waste, recycle, reuse, Sub-Saharan Africa

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1. INTRODUCTION

Solid Waste Management encompasses a set of activities that ensures that discarded materials are collected, source separated, stored, transported, processed and treated, such that useful components can be captured and reused or recycled, while residues are appropriately disposed of. Solid wastes may be broadly grouped into two major categories – municipal solid wastes (which may include wastes from households, the community and industries) and agricultural solid wastes (which include residues following harvesting and agro-industrial processing). In terms of importance to the national economy, health and sanitation, the management of municipal solid waste is far more important than that of agricultural solid waste.

Municipal solid waste management (MSWM) is a major responsibility of local governments, typically consuming between 20% and 50% of municipal budgets in developing countries (Fiafor, 2010). It is a complex task which ideally depends as much upon organization and cooperation between households, communities, private enterprises and municipal authorities. This is because the sustainability of municipal waste management system depends on the selection and application of appropriate technical solutions for waste collection, transfer, recycling and disposal. In Ghana, waste management is inadequate: a significant portion of the population does not have access to a waste collection service and only a fraction of the generated waste is actually collected and processed. With increasing waste generation due to increasing population density, agro-processing, improved lifestyles and poor citizen education on waste management and environmental sanitation issues among others, there is a pressing need, perhaps now than ever before, to improve on the waste management situation.

First and foremost, waste management is an essential task which has important consequences for public health and well-being, the quality and sustainability of the urban environment and the efficiency and productivity of the urban economy (Schubeler, 1996; Boadi and Kuitunen, 2003; Fobil et al., 2008). Secondly, the cities need to be kept clean and attractive for the strategic reason of accomplishing government policy of attracting tourists and foreign investments into the country to facilitate economic growth. Thirdly, closing the nutrient loop through recycling of the organic fraction of the waste stream into compost and/or biochar and its application in agriculture will help develop market for the sustainable use of the products and generate revenue for the maintenance of the compost and/or the value addition facility, improve on the soil fertility and reduce the use of inorganic fertilizer application. This will result in significant financial savings whilst cleaning and improving on environmental sanitation.

The municipal solid waste characteristics and quantity is a function of the agricultural and industrial production of the nation, lifestyle and living standards of the residents in the region. Generally, the solid waste generated in the developing countries is different in composition and quantity from that of the industrialized countries. Studies in Ghana revealed that 60–70% of the municipal solid waste is organic (Carboo et al., 2006; Fobil et al., 2002; Hogarh et al., 2008). Typical waste characteristics of the developing nations include (1) high waste densities, (2) high moisture contents, (3) large organic fraction, (4) cities with sweeping as well as open ground storage characterized by large amount of dust and dirt.

2. SOLID WASTE GENERATION IN GHANA

2.1. Municipal Solid Waste

Based on an estimated national population of 20 million and an average daily waste production per capita of 0.45kg, Ghana generates annually about 3.3 million tonnes of solid waste (EPA, 2002). For instance, Accra with an estimated population of 3 million and a floating population of nearly 300 thousand generates about 1,500 tonnes of solid waste/day (EPA, 2002). Approximately 1,800 metric tonnes of waste was reportedly generated daily in Accra in 2005 (AMA, 2005; Table 1). In 2009, around 2000 metric tonnes/day was generated in Accra (AMA, 2009), while the daily tonnage in 2010 and 2011 were approximately 2700 and 3000 metric tonnes, respectively (Zoomlion Company Limited, personal communication). The amount of municipal solid waste generated nationally in Ghana, categorized by region, is presented in Table 2. Clearly, the greatest amount of waste was generated in the Greater Accra Region, which hosts Accra, the national capital. This is followed by the Ashanti Region, which also hosts Kumasi, the second biggest city in Ghana. Altogether, approximately 10756 and 12017 metric tonnes of waste were generated in Ghana in 2010 and 2011, respectively (Table 2). Given the anticipated population increases in the near future, and urbanization, determining solutions for solid waste management in Accra and the major cities in Ghana has become an extremely critical issue. The subject is especially critical in low-income areas, which are particularly susceptible to the negative effects of poorly managed municipal solid wastes (http://mci.ei.columbia.edu/files/2013/03/Accra-MCI-solid-waste-report-FINAL-DRAFT-2010.pdf).

The cost involved in the collection, transportation and final disposal of these wastes is huge and very alarming. It reportedly costs the Accra Metropolitan Assembly (AMA) ¢ 2.5 billion (approximately US$ 250000 at the time) a month to clean up the city; plastic wastes constituted about 50 percent of that waste (Baitie, 2007). In Kumasi, the Kumasi Metropolitan Assembly (KMA) spent about 20 percent of its budget on solid waste management, although its cost recovery was only 5 percent of the expenditure (Obiri-Opare and Post, 2002).

The percentage of organic material in the waste stream in urban areas however has declined between 1994 and 2002 (Figure 1). While the percentage of organic waste in the waste stream declined from 85% to 60%, the contents of plastic and paper, as well as those categorized as “others” increased. The composition of glass and metals did not vary much over the period. This shows that the waste stream composition is quite dynamic over time in Ghana. This could be due to changing lifestyles that would affect waste stream composition (Fobil and Hogarh, 2006). The use of plastics and paper packaging has changed the organic waste composition from about 85% in 1994 to about 60% in 2002. Nevertheless, 60% of waste fraction being organic is still high.

The relatively increased contents of plastic and paper in the waste stream is an opportunity for these materials to be properly captured and recycled. The increase in content of other wastes (miscellaneous) from 3% to 13% in nearly a decade suggests that the waste stream is becoming more heterogeneous in Ghana (Figure 1). Waste management policies in Ghana must therefore continuously evolve to reflect these dynamics for development of appropriate management practices.

Table 1. Waste generation and service coverage in the five large cities in Ghana

City	Population	Daily waste generation (tonne)	Average daily collection coverage(tonne)	Average daily collection coverage (%)
Accra	3,500,000	1,800	1200	67
Kumasi	1,300,000	1,000	700	70
Tema	500,000	250	200	80
Tamale	310,000	180	85	47
Sekondi-Takoradi	300,000	250	165	66

Source: AMA, 2005.

Table 2. Daily amount of waste generated in Ghana in 2010 and 2011

Region	Daily amount of waste generated in 2010 (tonnes)	Daily amount of waste generated in 2011 (tonnes)
Greater Accra	2761. 4	3087
Ashanti	2350. 6	2631. 1
Western	558. 1	554. 8
Central	1063. 1	1274. 7
Volta	568. 7	576. 1
Eastern	1210. 4	1491. 1
BrongAhafo	1412. 3	1411. 4
Northern	332. 7	474. 6
Upper West	256. 1	255. 9
Upper East	242. 4	260. 5
Total	10755. 9	12017. 3

Source: Zoomlion Company Limited.

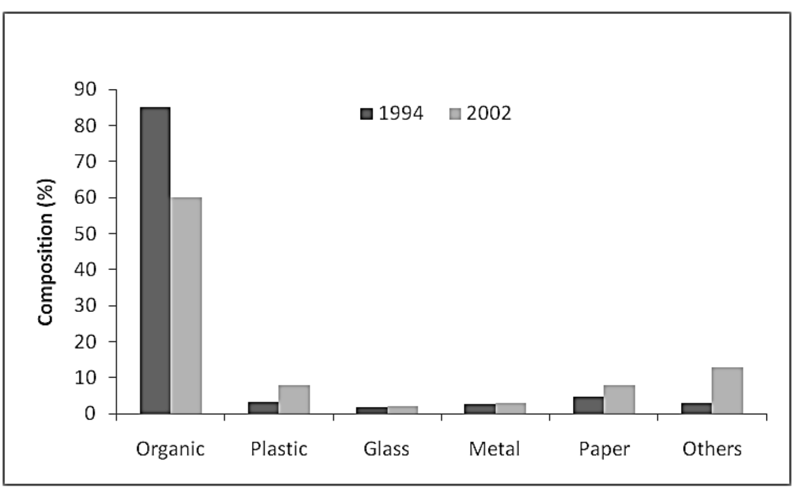

Figure 1. Municipal solid waste composition in Ghana. Adopted from Asomani-Boateng (1994) and Fobil et al. (2002).

2.2. Agricultural/Agro-Industrial Solid Waste

The agricultural sector employed over half of the population on formal and informal basis and accounted for approximately 21% of GDP in 2013 (Ghana Statistical Service, 2013). It is an important economic activity in Ghana and generates considerable amount of solid wastes. This sector is characterized by a large number of dispersed small-scale producers, employing manual cultivation techniques, and dependent on rainfed with little or no purchased inputs (Duku et al., 2011) and a few large agricultural estates, mainly for the oil palm, rubber and rice industries. The livestock sector is also characterized by mainly small to medium sized poultry houses, cattle ranches that are dispersed in the northern and coastal regions. The agro-industrial wastes/residues that are produced in large quantities and concentrated near the area of production or processing include sawdust, empty fruit bunches (EFB), palm oil mill effluent (POME), mesocarpfibre (MF) (generated during palm oil processing), palm kernel cake (PKC) and rice husk. The EFB has a high moisture content of approximately 55-65%, high silica content and form 25% of the total palm fruit bunch. It is composed of 45-50% cellulose and about equal amounts (25-35%) of hemicellulose and lignin (Deraman, 1983). Together, EFB and POME form the largest by-products of palm oil processing. For most mills, POME and EFB are still considered as unwanted waste mainly because of their storage, transport, distribution and treatment costs. Other major residues generated from harvesting and processing of cereals (maize and sorghum such as maize/corn straw and cob, and sorghum straw and rice husk.

Based on annual production of approximately 3,135,000 tonnes of fresh oil palm fruit bunches (calculation based on an average yield of 11 tonnes per hectare) (Toledano et al., 2004), an estimated 721,000 tonnes of empty palm bunch is released into the environment yearly. Similarly, based on annual production of approximately 400,000 tonnes of cocoa beans (Ofosu-Budu et al., 2001), an estimated amount of 550,750 tonnes of dry cocoa husk is produced yearly. The wood industry churned out 2,001,466 m^3 of sawdust in 1987 from only 8 major locations, in Ghana (Ofosu-Budu et al., 2001). The amount of poultry droppings and cow dung released to the environment is equally quite significant although data is not easily available, however, poultry population has been increasing steadily, with current population of over 18 million (Ghana Statistics Service, 2002). It is estimated that total cattle wet and dry manure produced in the country in 2008 were 22.8 million and 2.9 million tonnes, respectively (Duku et al., 2011).

3. Challenges to Solid Waste Management in Ghana

In most cities of developing countries, waste management is inadequate, in spite of allocation of substantial amounts of their budgets to this sector (Fiafor, 2010). This is because a significant portion of the population does not have access to a waste collection service and only a fraction of the generated waste is actually collected (Schubeler, 1996, Oteng-Ababio, 2014). Most often than not, the cost of managing the waste is far higher than the resources income/revenue generation or the funds that has been allocated for its management.

3.1. Lack of Adequate Human Resources, Logistics, Accurate Database

Managing waste is a complex task that requires changes in consumption and waste production patterns, appropriate technology, organizational capacity, and co-operation among a wide range of stakeholders (Zarate et al., 2008). Proper management of solid waste requires that the managers know the amount and composition of waste that is being generated. This is because every manager should know exactly what material he is dealing with and the quantities he is managing. The solid waste management system in major cities and towns in Ghana is constrained by a lack of competent personnel with the requisite technical expertise for solid waste planning, logistics, operation and monitoring, and landfill design and operation. Many of the workers, particularly among the small-scale firms, have little or no training in waste management. For an effective and efficient solid waste management system, there is the need for the waste stream to be characterized by their sources, types, generation rates and composition. Accurate data on solid waste will enable effective monitoring, controlling existing waste systems, and also help in making regulatory, financial and institutional decisions. Unfortunately, the solid waste management system in Ghana, especially in the major cities, does not have such accurate database. The lack of accurate data on solid waste generation and characteristics impedes any sustainable waste management programmes for the cities and towns. This could partly explain why the authorities, have often failed in the selection of appropriate technology for solid waste management. The use of compactor trucks, for instance, reflects a lack of knowledge of the characteristics of the wastes generated in the city. Considering the fact that organic matter forms the bulk of the solid waste in the city, compaction may tend to squeeze leachate out of the waste and pose possible health threats. Also, compactor trucks are not suitable for the small, untarred, inaccessible roads in many parts of the city.

3.2. Lack of Proper City Layout and Good Road Network

The lack of comprehensive land use planning in Accra and other major cities in Ghana have resulted in the cities reeling under indiscipline, haphazardness, and the lack of an adequate and well maintained infrastructure in the urban, and industrial development processes. The absence of properly laid down streets and too narrow, and untarred roads, particularly, in slums, make it difficult for waste collection vehicles to reach some parts of the major towns and cities. Also, uncontrolled expansion has resulted in an increase in the average travel distance to be covered by collection vehicles and additional cost to waste management.

The coverage of waste collection in Ghana is far from adequate. Presently, no city in Ghana enjoys 100% coverage of waste collection (Table 1). Among the major cities, Tema recorded the highest coverage of 80%, presumably because Tema is relatively well planned and residents have averagely higher income and most homes subscribe to the services of waste collection companies. In smaller cities like Tamale, less than 50% coverage has been reported (Table 1).

3.3. Challenges of Waste Collection

The mode of municipal waste collection in Ghana differs considerably and is dependent on the locality and income levels. In high income communities, households engage the services of waste collection companies. In low income communities where people cannot afford to contract the services of waste collection companies, individuals carry their wastes to designated communal waste collection points (waste transfer stations). Waste collection in middle income communities is a mix of household and communal collection. On a nationwide scale, only 4.8% of households were reportedly served by household waste collection (Ghana Housing and Population Census, 2000). This result is due to the fact that the rural communities and the urban poor, who constitute a large proportion of the population, are unable to access household waste collection. As a result, about 7.9% of the Ghanaian population burned household refuse, while 57.6% send their refuse to communal sites and refuse dumps (Ghana Housing and Population Census, 2000). The remaining 26% of households dumped their refuse at unapproved locations including open spaces, gutters and drains, and at the embankment of rivers, lakes and wetlands (Figure 2).

Figure 2. Solid wastes thrown into open drainage in Accra, Ghana.

Waste collection and transport were previously handled entirely by the Metropolitan, Municipal and District Assemblies (MMDAs). However, several operational challenges necessitated the invitation of the private sector in the municipal solid waste management, and that eventually led to the adoption of a public-private partnership (PPP) for waste collection and transport in Ghana. Presently, the collection and transport of municipal solid wastes MSW in Ghana is outsourced to private entities, while the MMDAs play a supervisory role. Under this arrangement, different waste management companies are assigned to operate in specific zones within the metropolis of the major cities.

In spite of this initiative, a sizeable quantity of MSW is left uncollected in the major cities in Ghana (Table 1), and this has led to a situation where there is indiscriminate disposal of waste in surface drains, canals and streams, creating unsanitary and unsightly environments in many parts of the cities and municipalities. The environment is still overwhelmed with indiscriminate and irresponsible dumping of waste in street corners, in between houses, in gutters, drains and water ways.

3.4. Lack of Containers and Irregular Waste Collection Days

Urban residents are still faced with inadequate containers and/or equipment for storing and transporting solid waste, lack of definite schedule for collecting waste from storage to disposal point. Waste collectors may show up every week, every three weeks or after one month; such erratic waste collection program leads to an overflow of garbage at storage points. Lousy transportation system where the garbage been conveyed in trucks are left uncovered and end up falling off the trucks and littering the very street they are trying to keep clean. The private sector participation has not led to any significant improvement in MSW management due to constraints, including lack of financial, technical, logistics, and enforcement of bye-laws and human resources.

3.5. Technological Challenges

Most of the technology employed in solid waste management in Ghana has been largely adopted from the industrialized countries, without much or any local adaptation. In view of the fact that proper MSW management involves several factors such as solid waste type, social perceptions and attitudes, financial obligations and income levels of residents, it is important to develop, adapt and introduce local content to the solid waste management technology in the country. Waste management solutions in one region might not necessarily be appropriate elsewhere**.** The wholesale adoption of waste management technology has brought technical and financial problems associated with such industrialized technology that are exerting much pressure on the limited budget for the waste management system. The technical expertise for the maintenance of this advanced technology is limited in the country. As a result, facilities and vehicles often break down and this often temporarily halts services to parts of the cities.

The adoption of advanced and foreign waste technologies often requires heavy capital investment and skilled engineers to manage such facilities. In 1979 when Ghana decided to adopt a large-scale centralized composting facility (the Teshie-Nungua Composting Plant), the facility did not last a decade because it was beset with major technical breakdowns, particularly mechanical and electrical failures such that it never operated at full capacity after an initial breakdown in 1986. The lack of local technical expertise at the time hindered the fixing of the problem. Part of the technological challenges related to the design of this facility. The design was such that the compost was produced from unsegregated waste. The feedstock for production consisted of degradable organic material mixed with plastics, metals and other non-degradable materials. The non-degradable fractions were removed only after composting by passing the compost product through an automated mechanical sieve (a separating device) (Figures 3 and 4). This sieve broke down frequently because of increased content of non-degradable materials. At the time the plant was designed, organic waste constituted about 80 – 90% of the solid waste stream in Accra, but no allowance was made for such changes in the feedstock with time.

Figure 3. Un-sieved compost full of foreign materials such as plastics and metals.

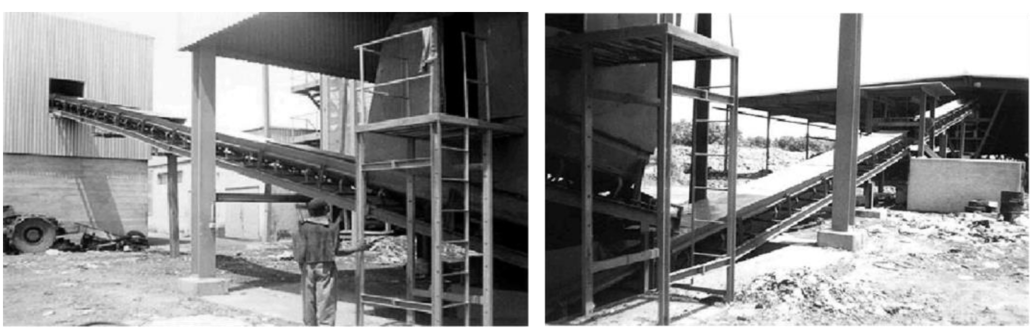

Figure 4. Decommissioned composting plant at Teshie-Nungua showing the system that was applied to convey and sieve mixed-waste compost.

As lifestyle changed with improved income levels, the contribution of plastics, tins, cans and bottles increased in the waste stream, such that organic fraction was reduced to averagely 65%, and the automated separating device become less effective and operated at much reduced efficiency. The frequent failure of the separating device meant that sometimes compost production proceeded without removing non-degradable materials from the compost product. This reduced markedly the aesthetics and quality of the product, to the extent that sometimes farmers rejected applying the compost.

Many of the existing mixed MSW composting facilities have an over-simplified design that focuses primarily on the production aspects of composting and inadequately addresses factors crucial to producing a high-quality and marketable product. For example, many facilities have limited capabilities to separate compostable materials from the non-compostable fraction before the composting process is begun. Because the quality of the end product is determined by the type of feedstock, inadequate separation of materials can negatively affect compost quality.

The failure to control the quality of the compost directly impacts on its marketability. As a result, market development has not kept pace with compost production, which in turn has led to under-capitalized projects. Odors associated with storing organics before composting and during composting pose a significant challenge for many facilities. The inability to adequately deal with potential or existing odor problems has contributed to agitation and confrontations between authorities and residents.

3.6. Financial Constraints

There is a fundamental problem of how the MMDAs can generate adequate enough money to pay for the collection and transport of solid waste in the cities. In spite of allocating between 20-50% of their revenue to waste management (Fiafor, 2010), the authorities still face huge financial challenges in managing MSW.

It has been advocated that a way forward would be to apply an economic tool by integrating the polluter pays principle (PPPe) into waste management in Ghana, such that people or consumers are made to pay for the disposal cost of managing the waste that they generate. The PPPe is a useful waste management tool, which when properly applied, would work. It generates sustainable funds for waste management whilst it creates economic incentives for waste minimization or source reduction.

3.7. Public-Private Partnership and Operational Difficulties

Operationalizing PPP in the waste sector in Ghana has reportedly improved waste collection and transport by about 25% and transformed the coverage of waste collection in the capital city of Accra to 67% (Table 1). The private waste haulers though have brought a lot of sanity into waste collection and transport in Ghana, are still confronted with challenges that limit their performance. There have been several situations where the MMDAs have defaulted in payment for close to two years. Consequently, many of the waste hauling companies are unable to meet their recurrent expenditure for solid waste collection. Other options in generating sustainable income to subsidize the management of MSW, such as adding value to the compost, which are often of low quality, to meet specific markets, or use as feedstock for community biogas development, should be explored.

3.8. Lack of Adequate Education and Community Involvement

Several attempts have been and continue to be directed at addressing the management of the organic waste fraction, but without much success. This could be partly due to the lack of cooperation from residents, as a result of inadequate engagement; education and involvement of the population in the management of waste as a collective effort, the adoption of technologies developed in the industrialized countries without much adaptation to suit the local conditions and training of personnel.

Waste management practices require substantial public education efforts because they usually require some changes in the public's waste generation and management behavior. For example, new source-separated programs require residents to change the way they sort discarded materials. Compliance to various waste management programs requires substantial public education, and willingness on the part of the public to change individual attitudes. This is a major area of concern in waste management in Ghana, as it has been difficult to change old attitudes for pursuance of new waste management paradigms. Perhaps a way forward is to teach the principles, practices and importance of sanitation and waste management in all educational levels. For instance, source separation of solid waste could be included in school curricula and taught right from primary schools, such that children are introduced to this simple but powerful waste management concept during the early years of childhood development. It thus, becomes more practicable for children to carry the habit of source separation of solid waste into adulthood and practice it in their homes and places of work. People are either ignorant or just won't bother with waste matters. A consistent educational programme in the media and enforcement of bye-laws will remind people of their bad habits and keep them in line. Clean cities giving rise to healthier productive populations.

The level of community education and commitment in waste management as a shared responsibility between town and city authorities and residents is virtually non-existent. Most residents in these communities think that they are paying for a service, which they should enjoy at all cost, albeit at a low fee and are less educated about their responsibilities to promote safer and sanitized environment.

3.9. Dumping of Unsegregated Waste to Dumpsites/Landfills

Another major difficulty in solid waste management in Ghana is that virtually everything is landfilled in crude dumpsite, which usually consists of very deep depression at old quarry sites. As waste is not segregated at source, it is often difficult to capture various recyclable materials. Therefore waste materials such as organics, plastics, metals, paper and clothing are all dumped together and often burnt at the dumpsite. This practice shortens the lifespan of the landfill and also generates methane and leachates that impacts negatively on the environment, because of the high organic matter component and the environmental conditions that promotes anaerobic decomposition. There is the need to educate and seek the cooperation and involvement of the community about the need and importance of source separation in MSW management.

3.10. Lack of Adequate Sanitary Landfill Sites

The final disposal practices in almost all communities in Ghana include crude open dumping, controlled dumping (without any environmental impact assessment) and uncontrolled open burning. Open dumps are characterized by the lack of engineering measures, no leachate management, no consideration of landfill gas management, and few, if any, operational measures such as registration of users, control of the number of "tipping fronts" or compaction of waste (Zerbock, 2003). Presently, there are only two engineered landfills in Ghana, one in Kumasi and the other in Tamale. Regrettably, the capital city, Accra with the highest amount of waste generation, has no sanitary engineered landfill; often refuse are disposed of in abandoned quarry pits and large dumpsites. Currently, the selection of landfills is without regard to nearness of water bodies, and other factors, including specific characteristics of the subsoil, ground water conditions, topography, prevailing winds and the adjacent patterns of settlement and land-use.

In developing countries, open dumpsites are the most common method of disposing of waste (World Bank 2012). The single major determinant factor in locating dumping sites is access to collection vehicles rather than ecological or public health considerations. Lack of financial and human resources coupled with the absence of enabling policies, make it impossible to operate and maintain disposal sites at minimum sanitary standards. Because of the poor management of final waste disposal sites in Ghana, land owners and residents are unwilling to provide land for landfill projects and this could be a primarily factor to explain why Accra is without an engineered sanitary landfill. An attempt to construct a landfill at Kwabenya, a suburb in Accra, was met with fierce resistance from the community and the project was subsequently cancelled.

3.11. Lack of Proper Policies and Enforcement

3.11.1. Compost Plants and Source Separation

As part of the overall waste management policy, compost plants are to be developed and managed as part of all categories of final disposal sites. The target is to compost 50% of biodegradable organic fraction of the municipal refuse that will be source separated (NESSAP, 2010). Although the strategy sought to build several mechanized and manual composting plants across the country in Metropolitan, Municipal and District Assemblies (MMDAs), not much has been achieved so far. Since the rolling out of this policy, only one compost plant has been established, under the public-private partnership arrangement.

The MMDAs supported by the Ghana Environmental Protection Agency (EPA) are also encouraged to facilitate primary separation of municipal solid wastes at household, community and public levels. Source separation is a vital component to any composting strategy, as part of the overall strategy in waste management. It helps to capture the organic fraction of waste to produce high quality compost. The 2010 National Environmental Sanitation Strategy and Action Plan (NESSAP, 2010) proposed a gradual integration of source separation at progressive rates of 20% by 2013, 25% by 2015, 70% by 2025 and 90% by 2035. Unfortunately, for many years, source separation has not been enforced as part of Ghana's waste management strategy. The target for 2013 has not been achieved at present and it is unlikely the 2015 target would be met. Source-separated programs require residents to change the way they sort discarded materials as well as separating out household hazardous wastes. The inability of municipal authorities to provide adequate education to the public could be a factor in the non-compliance of the source separated program. The education program on source-separation should provide the public on the objective, factual information about the importance of the program and the anticipated results and its overall importance to the sanitation issues and well-being of the society. Most importantly, the effect of the source-separated program on the product quality after recycling and its effect on the market value, and role in revenue generation should be stressed. The revenue generated could be used to subsidize the over-all program and reduce waste taxes that the consumers may pay. Weak enforcement of environmental regulations - which allows local authorities to flout environmental regulations without any sanctions - has all contributed to compound the problem.

3.12.2. Compost Quality

The role of composting the organic fraction of the MSW as a strategy in MSW management is widely acknowledged by the government. Composting and agriculture generally are considered to be a natural fit. Increasing environmental constraints on the disposal of municipal and agricultural solid waste and a growing understanding of the agronomic benefits of compost utilization suggest that composting is an obvious win-win solution for farmers. However, for composting to continue its growth as a waste management alternative it will be necessary to develop a clear understanding of the economic implications of managing solid waste with composting and of using compost in agricultural and horticultural applications. As an emerging market, the quality issues on compost should be addressed and enforced vigorously. The country is yet to set out a policy on standards for compost quality, in terms of nutrient content and most importantly regarding permissible levels of pathogens and vectors for use in horticulture. It is important to address this policy issue since the type of feedstock affects the quality of the compost, its application and use in horticulture and societal acceptance. These parameters among other determining factors could vary from country to country. Currently, the compost quality standards of the developed nations are used for local assessment. However, not much effort has been given to the quality, uses and development of markets for the products.

The current policy on composting of organic waste in Ghana appears targeted at only MSW and silent on agricultural waste. The policy should also cover all biodegradable waste materials and active effort should be made to capture this fraction of waste at all levels of socio-economic engagements.

4. THREAT OF IMPROPER MANAGEMENT OF MSW TO ENVIRONMENT

4.1. Environmental Pollution and Human Health Threats

The potential threats of waste management in Ghana mostly concern environmental contamination and risk of exposure to various environmental hazards. The organic fraction constitute about 60% of the waste stream in Ghana and largely biodegradable. The high organic content of solid waste in Ghana has peculiar environmental health challenges if not managed properly.

First of all, the organic fraction of the waste decomposes very fast under the prevailing hot tropical environment generating obnoxious gases (methane, nitrous oxides) that pollute the atmosphere. Secondly, the contamination of water bodies-leading to spread of water-borne diseases, health hazards from the stench emanating from uncollected and decaying garbage, air contamination, garbage-chocked drains and gutters, the plastic waste menace, and irresponsible disposal of refuse in communities are some of the threats to the livelihood and health of the population and challenges to the authorities who are supposed to manage the waste. Thirdly, the organic portion of the solid waste stream serves as sites for disease causing vectors, parasites and rodents, where they can feed and reproduce.

4.2. Open Dumpsites

The use of open dumpsites and non-engineered landfills as final disposal points of waste is a major source of environmental contamination. Open dumpsites and non-engineered sanitary landfills contaminates the air, soil and nearby water resources. Dumping of mixed waste occurs alongside open burning, grazing of stray animals and pollution of surface and groundwater by hazardous substances such as leachate and gas (UNEP, 2011). Dumpsites have been found to emit or produce toxic chemicals such persistent organic pollutants (POPs) (Essumang et al., 2009; Hogarh et al., 2012; Takahashi et al., 2013) and heavy metals (Agyarko et al., 2010; Osei et al., 2011; Feldt et al., 2014; Itai et al., 2014) and also linked to many harmful health effects, including skin and eye infections, respiratory problems, vector-borne diseases such as diarrhoea, dysentery, typhoid, hepatitis, cholera, malaria and yellow fever, high blood lead levels and exposure to heavy-metal poisoning (UNEP, 2011). For instance, soils at waste dumpsites are heavily laden with heavy metals (Agyarko et al., 2010; Itai et al., 2014). In instances where soils from abandoned dumpsites have been applied in vegetable cultivations, significant uptake of toxic metals was reported (Odai et al., 2008).

The inability of city authorities to collect and properly dispose of the solid waste that result in significant quantity being left uncollected is a major threat to the environment. This results in choking of gutters, and is a major contributing factor to the seasonal and annual floods in Accra and the outbreak of waste-related diseases such as cholera and dysentery.

4.3. E-Waste

An emerging area of concern regarding the scavenging of metal waste in Ghana is the informal recycling of electronic waste (e-waste). Much of the e-wastes in Ghana are collected by individuals and sent to an informal e-waste recycling site at Agbogbloshie, a suburb of Accra. The process of recovering valuable metals such as copper and aluminum from the e-waste consists of open burning of the e-wastes and melting off the PVC coating of metal wires. Accompanying these processes are thick fumes potentially hazardous to humans and the environment (Hogarh et al., 2012). Thus, for the opportunity in e-waste recycling to be harnessed, there must be a departure from the present methods of informal recycling activities.

4.4. Pathogens at Open Dumpsites

Open dumpsites are also a haven to disease causing organisms. They provide a conducive environment where vectors of malaria, cholera, typhoid and many other diseases thrive. Disease carrying rodents may also invade open dumpsites and later transfer pathogens to the domestic environment. The other issue with open dumpsites is that scavengers flood these sites in search for plastics and metals to be sold to recycling facilities. They undertake this activity without any protective gear and at the peril of their health (Figure 3).

Figure 5. Scavenging at an open dumpsite in Ghana.

4.5 Open Uncontrolled Burning of Waste

According to a survey conducted in 2000, about 7.9% of the population burned household refuse (Ghana Housing and Population Census, 2000). Such uncontrolled open burning of waste causes the release of many toxicants including carbon monoxide, persistent organic pollutants (such dioxins, furans, polychlorinated biphenyls (PCBs), polychlorinated naphthalenes (PCNs), polycyclic aromatic hydrocarbons (PAHs)), heavy metals and a suite of many other chemicals into the environment (Hogarh et al., 2012; Takahashi et al., 2013; Feldt et al., 2014; Itai et al., 2014). In addition, soils at waste dumpsites are heavily laden with heavy metals (Agyarko et al., 2010; Itai et al., 2014).

In instances where soils from abandoned dumpsites have been used for vegetable cultivations, significant uptake of toxic metals has been reported (Odai et al., 2008). Because waste is constantly burnt at open dumpsites, those living nearby are exposed to the smoke and toxic fumes emanating from the sites.

This activity exposes nearby residents to greater risk from acute respiratory infections, and also affected the value of residential properties in the vicinity of dumpsites/non-engineered landfills, since people are unwilling to stay close to such facilities (Owusu et al., 2014).

5. Threat of Improper Management of Agricultural/ Agro-Industrial Solid Waste to Environment

5.1. Crop Residues

Together, EFB and POME form the largest by-products of palm oil processing. For most mills, POME and EFB are still considered as unwanted waste mainly because of their storage, transport, distribution and treatment costs.

The high transportation and distribution costs, long degradation time (up to one year), water pollution by the rest oil (about 1.25%) and its attractiveness for beetles (Ofosu-Budu 2006) have been a number of challenges facing the management of the EFB that are hardly solved. Improper handling of harvested blackpod infected cocoa pod husk could serve as source of inoculum for the reinfection of healthy pods during rains (Gregory and Maddison, 1981).

Sawdust also contains germination inhibiting substances i.e., phytotoxic organic metabolites (Zucconi et al., 1981; Garcia et al. 1992; Marambe and Ando, 1992; Ayuso et al., 1996) which might affect crop production if used directly without processing. Some phytotoxic metabolites are acted upon by microbes during composting thereby inactivating them or reducing their concentration (Garcia et al. 1992; Ayuso et al. 1996).

5.2. Animal Waste

Poultry droppings contain pathogens and eggs of parasites that could pose serious health hazards to human population. The use of manures provides an important outlet for the reuse and recycle of byproducts generated by the animal industry. Manure may contain antibiotics and naturally occurring steroidal hormones that may pose a threat to the environment, such as the endocrine disrupting chemicals.

6. Opportunities to Recycle Solid Wastes in Ghana

Ultimately, waste management presents an opportunity, not only to avoid the detrimental impacts associated with waste, but also to recover resources, realize environmental, economic and social benefits and to take a step on the road to a sustainable future. Decision makers, responsible for planning and policy making, need to be well informed in order to develop integrated waste-management strategies adapted to the needs of citizens (Guerrero et al., 2013).

Several opportunities exist that shows that agricultural and municipal solid waste generated can be recycled to generate revenue to supplement the cost of waste management. These include recycling, composting, biochar, and biogas generation. Duku et al. (2011) has reviewed comprehensively the potentials of using biomass for biochar production in Ghana.

6.1. Diversion of Organics from Landfills

The greatest opportunity for developing countries to reduce the volume of waste in the waste stream rests on their ability to divert the organic and other recyclable fractions away from landfills. The reduction of waste to the landfill can be done through source separation into organic and others, reuse of some of these waste (e.g., bottles) thereby reducing the quantity of waste to the landfills. This practice will eventually prolong the lifespan of the landfills.

6.2. Scavenging Activity

Waste scavengers play a critical role in the recycling of plastic and metal wastes in Ghana (Figure 5). Plastic wastes presently constitute about 10% of the waste stream in Ghana (Fobil and Hogarh, 2006) and is likely to increase. The National Plastic Manufacturers Association offers services of collecting and buying plastic waste materials for re-sale to recycling industries. This has created opportunities for itinerant waste buyers who trek from house to house to buy plastic waste, or scavengers who pick plastic wastes from dumpsites and sell for profit. There is a high demand for recycled plastic material in Ghana. Unfortunately, data on the quantities of plastic materials recycled in Ghana have not been established due to poor record keeping. One such potential market is Blow Plast Industry Limited, which recycles plastic waste. It has installed a facility with a daily capacity to process 24 tonnes but currently process only 7 tonnes (Oteng-Ababio, 2010).

Scavengers also look out for ferrous metals that are sold to local metal fabricators and the metal industries in Ghana. Significant quantities of these metal wastes were exported to China and other Asian markets, prompting the Steel Manufacturers Association of Ghana (SMAG) to lead a public campaign for a complete ban of the export of metal scraps, as a result of shortfalls on the local metal market. Metals, particularly, aluminum, are recovered and sold to small-scale recyclers who use them to produce valuable items, such as lamps, cooking pots, and washing pans. The export of scrap metals is presently banned in Ghana, with the hope that scavengers would be compelled to offer scavenged metals to feed the local metal industry.

6.3. E-Waste Recycling

An emerging area of concern regarding the scavenging of metal waste in Ghana is the informal recycling of electronic waste (e-waste). It is estimated that about 215,000 tons of electrical and electronic equipment were imported into Ghana in 2009, with as much as 70% being used items and destined to soon become e-waste (Amoyaw, 2011). Much of the e-wastes in Ghana are collected by individuals and sent to an informal e-waste recycling site at Agbogbloshie, a suburb of Accra. Valuable metals such as copper and aluminum are recovered from the e-waste by crude methods at this site.

6.4. Recycling of Agricultural Waste

Traditionally, most of the agricultural residues generated in the country are scarcely utilized. Except for the wastes that are generated and localized near processing sites, collection and utilization for either bioenergy or biochar production could be difficult due to technical constraints, ecosystem functions and other uses. Agricultural solid wastes including sugar cane (bargasse), corn cobs, and coconut shells are used to smoke fish in open ovens, in low income fishing communities. Similarly, oil palm empty fruit bunch is used as fuel to boil palm fruits during processing, or used as mulching agents in oil palm nurseries and plantations (Ofosu-Budu, 2006). The collection and use of these wastes provides employment for people who collect them for sale to fish smokers**.** There is currently no reliable information on the percentage that is utilized and for what purpose.

7. Composting of Municipal Solid Wastes in Ghana

Considering the huge fraction of organic material in MSW (about 60%) and the fact that waste biomass is almost entirely decomposable, composting and technologies that utilizes organic wastes are technically ideal to manage these categories of wastes in Ghana. Composting process is an environmentally sound and beneficial means of recycling organic materials, not a means of waste disposal. Composting is the biological decomposition of biodegradable organic material under controlled conditions to a state sufficiently stable for nuisance-free storage and handling for safe use in land application (Diaz et al., 1994). Composting and co-composting are two commonly used terms. Composting is a broader term that includes co-composting. While composting refers to the decomposition of any organic material (also referred to as “feedstocks”), co-composting is the composting of two or more feedstocks with different characteristics.

Composting is carried out by successive microbial populations that break down organic materials into carbon dioxide, water, minerals, and stabilized organic matter. Carbon dioxide and water are released into the atmosphere, while minerals and organic matter are converted into a potentially reusable soil-like material called compost. The loss of water and carbon dioxide typically reduces the volume of remaining material by 25% to 60% (Tchobanoglous et al., 1993).

7.1. Composting Technologies

There are two basic composting technologies: windrow-based and in-vessel technologies. The windrow-based type is popular in Ghana. In the windrow-based technology, organic waste is brought to a central open-air facility and formed into windrows (heaps) with heights ranging from 1 m to 1.5 m. The windrows are turned periodically to facilitate aeration, maintain a stable temperature and rate of decomposition. Water is added to maintain suitable moisture content, usually around 60%. After the desired level of decomposition is reached and curation is achieved, the composted product is ready for assembly and distribution to end-users.

7.1.1. Backyard/Residential Composting

Backyard or residential composting is practiced in a few homes in the major cities. One common feature of homes that practice backyard composting is that they have large compounds and are located in the affluent suburbs of the city. The residents are engaged in the composting mostly for domestic horticultural purposes. Household composting is a simple way to manage domestic refuse that is generated in the kitchen and garden, effectively reduces waste quantities for collection and transportation to landfills. The composting unit consists of simple wooden receptacles, with variable sizes into which all compostable organic wastes generated at home are channeled.

7.1.2. Decentralized Community Composting

Decentralized composting is normally practiced at a community scale and provides small groups a way to compost at a relatively low cost. The feedstock is different from household composting in that it is more varied and exposed to contaminations, especially from plastics that are usually used for packaging of goods sold at the market places and other different non-compostable materials from both household and commercial sources. Between the late 1990s to early 2000s, the Asiedu-Keteke Sub-metropolitan Assembly in Accra undertook a mini-composting project, which exemplified decentralized community composting. The project involved the pooling of mixed solid wastes from households, commercial establishments and institutions in the Asiedu-Keteke area for composting. The mixed waste was heaped in the open for about three (3) to six (6) months with regular turning. There was no clear cut parameters for maturity determination and compost quality and this accounted for the varied periods at which the composts were harvested. There was no facility to separate the mixed waste stream into organic and other fractions before composting. After composting however, a screen was used to sieve the compost to remove contaminants such as broken bottles, plastics and rubber remnants, metals and many others. The compost was then bagged and offered for sale. The lack of appropriate technology to ensure high quality compost and effective marketing strategy affected the financial sustainability of the project that led to its premature closure.

Figure 6. (a) Un-sieved, (b) sieved composts and (c) manually operated sieving device applied previously in the community-based composting at Asiedu-Keteke in Accra, Ghana.

7.1.3. Centralized Large-Scale Composting

Centralized composting involves the use of large-scale, mechanized composting plant that normally demands a substantial level of financial investment. Solid wastes that are used for large-scale composting are gathered from a wider area and could be mixtures of refuse from all over a city or town. Centralized-large scale composting has the advantage of generating between 10 tonnes to more than 500 tonnes of compost per day; however it is very expensive to maintain (Hoornweg et al., 2000). Since centralized composting is on a larger scale, environmental, social and technical considerations are approached carefully, within appropriate jurisdictions for siting, designing, operations, maintenance and environmental compliance for waste delivery.

The first centralized large-scale composting plant in Ghana was established at Teshie-Nungua in Accra in 1979. Mixed refuse were brought to the site in tipper trucks from different areas in the Accra metropolis. The refuse were then heaped into windrows for at least three months. The composts were presumed mature when it turned black and humus-like, which takes between three and six months. The windrows were turned occasionally with heavy-duty trucks. Sewage sludge was also added occasionally to the compost heap, as a form of co-composting process to increase the content of nutrients such as nitrogen and phosphorus. The mature compost was conveyed to a magnetic separating device and a sieve, which together separated all foreign materials (metals, plastics, bottles, etc.) from the compost (Figures 3 and 4). It was then ready to be sold, either in bags or delivered in large quantities by tipper trucks to end-users.

The Teshie-Nungua composting plant was eventually decommissioned in 2011, having virtually degenerated into a mountain of solid waste dump from the 2000s. The collapse of the Teshie-Nungua composting plant seriously affected the management of organic waste in Accra. In 2012, under a public-private partnership (PPP) arrangement, Zoomlion Company Limited, a local waste management company in Ghana established a modern facility for waste sorting and composting in Accra. This facility has a capacity to process 300 tonnes of waste in an eight-hour shift. Zoomlion company is suffering from the same compost quality and marketing problems experienced by its predecessors, as a result of factors including unsegregated mixed waste stream as source of feedstock.

The metropolitan authorities have defaulted in payments for services rendered by the company regarding the collection and transport of waste, which has hindered waste transport to the composting facility and operations at the site. Clearly, large scale composting of municipal solid waste in Ghana has a lot of challenges. Community composting may be more suitable for developing countries like Ghana, since it does not involve hauling the waste over long distances.

8. Managing Agricultural/Agro-Industrial Wastes

8.1. Composting

The agricultural and agro-industrial residues, if managed properly like through composting, can be beneficial to agriculture, since these contain important plant nutrients such as nitrogen, phosphorus, potassium, magnesium and other nutrients (Adamtey, 2005; Mahimairaja,1993). Composting is the most suitable option among the wastes management strategies with economic and environmental profits since this process reduces the bulk volume of organic materials, eliminates the risk of spreading of pathogens, weed seeds or parasites associated with direct land application of manure and leads to final stabilized products, which can improve and sustain soil fertility. During composting the biological heat produced can reach a temperature of about 65°C, which is sufficient to inactivate most pathogenic bacteria, viruses and helminthic ova (Sterrett et al., 1983; Polprasert, 1996) that otherwise could infect the workers. Therefore the composted products can be safely disposed of on land, or used as fertilizers for plant growth.

The Forest and Horticultural Crops Research Centre (FOHCREC) of the University of Ghana at Kade has been involved in the co-composting of agricultural/agro-industrial wastes, notably EFB, poultry dropping, cow dung, rice straw, citrus waste, sawdust and palm oil mill effluent (POME) (Ofosu-Budu and Adamtey, 2002; Hogarh et al., 2008; Ofosu-Budu et al., 2010; Adamtey, 2005; Ivy, 2014). A collaborative effort between FOHCREC and Benso Oil Palm Plantation has led to the large scale production and utilization of compost produced from EFB and POME (Figure 7). Fruit wastes, mainly citrus wastes, has been successfully processed to a high quality compost suitable for plant growth, after co-composting with poultry dropping, rock phosphate, EFB and sawdust (Ofosu-Budu, unpublished). The phospho-compost produced was evaluated using maize as the test crop and a high phosphorous relative agronomic efficiency was reported (Ivy, 2014).

Despite the growing popularity of composting in Ghana, several significant challenges in developing and operating successful composting programmes exist. These include the following: developing markets and new end uses, inadequate or non-existing standards for finished composts, inadequate design data for composting facilities, lack of experienced designers, vendors, and technical staff available to many municipalities, problems with odors, problems controlling contaminants, inadequate understanding of the scientific basis of composting and inadequate financial planning (O’Leary and Walsh, 1995).

Figure 7. Large scale production of compost from empty fruit bunches (EFB) and palm oil mill effluent (POME) at the Benso Oil Palm Plantation in the Western region in Ghana.

8.2. Black Soldier Fly (BSF) Composting Technology

One of the limitations of open windrow compost technology is the long period it takes to mature. On the average, a minimum of three months is required for the compost to attain maturity. The importance of reducing the composting period to save time, money and space cannot be over-emphasized. The use of larvae of the black soldier fly (BSF, *Hermetia illucens*) in degrading organic material such as poultry manure, pig manure shows promising results and has the potential for use in composting municipal solid waste in respect to volume reduction of the waste and faster attainment of compost maturity. In addition, the emerging insect biomass is ideal as animal feed (Sheppard et al., 2002; Newton et al., 2005; Ogunji et al., 2007; Stamer et al., 2007). Once hatched, the larvae start to feed on the waste, such as rotting fruits and vegetables, animal manure and human excreta, kitchen waste, spoiled feed, and manure, which are the major constituents of MSW, and achieving a dry mass volume waste reduction of ~55% (Sheppard, 1983; Newton et al., 1995; Myers et al., 2008). While occupying the organic waste, the larvae aerate and dry it, thus, reducing odors. The larvae also modifies the manure, potentially reducing harmful bacteria (Erickson et al., 2004). The resulting larvae-manure is high in nutrients and energy and could be used as soil amendment or further in biogas-plants to produce biogas (Newton et al. 2005). Larvae of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae), may therefore be used in low and middle-income countries to transform organic waste into valuable animal feedstuff and compost in the form of their last larval stage, the prepupae.

The use of black soldier fly larvae therefore has a great potential in organic waste management, in the degrading of the organic fraction of municipal solid waste, especially market and food waste. However, certain limitations could exist, especially regarding the presence of heavy metals and plastics in the feedstock, and potential pathogen management which could negatively influence the growth and life history traits of the fly population and can accumulate in the prepupae. These and other challenges are been addressed, by scientists in Ghana (University of Ghana, Biotechnology and Nuclear Agricultural Research Institute) and FiBL, Switzerland through an on-going collaborative efforts to develop guidelines in the use of BSF larvae in degrading the MSW from urban markets.

8.3. Biochar Production

Biochar production from organic waste such as agricultural crop residues, forestry residues, wood wastes, animal manure and organic fraction of municipal solid wastes, is a useful process for recycling organic wastes (Duku et al., 2011; Galgani, 2012). Biochar is a form of charcoal produced when biomass is subjected to the thermochemical process of pyrolysis, which proceeds at low oxygen condition. The mineral ash constitutes 1–20% by weight, and are composed of nitrogen (N), phosphorus (P), potassium (K), silicon (Si), calcium (Ca), cadmium (Cd), mercury (Hg) and arsenic (As) (Duku et al., 2011). Biochar has very high carbon content, and serves as a sink for carbon when added to the soil. Application of biochar to soil improves soil nutrient retention capacity, increase soil pH of acidic soils, and improves on the water holding capacity. Therefore biochar production could achieve large agricultural and climatic benefits in Ghana where farmers cannot afford to pay high prices for soil amendments. The use of biochar as a carbon sink is significant because it reduces the potential of greenhouse gas emissions, particularly nitrous oxide (N_2O) and methane (CH_4) release (Duku et al., 2011). Galgani (2012) undertook a project in Northern Ghana and investigated composting, biogas and biochar production in the context of carbon markets and concluded that pyrolysis for biochar production could generate much more carbon revenues per unit of waste treated than composting and anaerobic digestion. Results from modelling of the pyrolysis of rice husks from the Tamale rice mill showed that carbon for about 1.5 t CO_2 eq per ton of rice husks charred could be sequestered (Galgani, 2012). Other organic residues with high lignin content that are potential feedstock for biochar production include sawdust, empty fruit bunch, rice straw, maize stubble and cobs. Despite the emerging importance of biochar for soil fertility improvement and as a carbon sink, its production has been based on advanced technologies that are expensive (Duku et al., 2011). A simple but effective and sustainable biochar production technique has been developed at the University of Ghana, FOHCREC in Ghana (Figure 6). In its crude form, the equipment consists of a barrel with both lids at the ends removed. The lower 40 cm part of the barrel is perforated to make a hole with diameter of 3-4 cm.

The inner part of the barrel is filled with wood which will be used to generate heat that will burn the feedstock. The feedstock (rice husk) is applied to cover the holes on the barrel wall. Fire is ignited to the inner side with the wood, and the feedstock is turned once in a while, such that the partially burned feedstock is turn outside gradually until, all the feedstock is partially burnt. The burnt feedstock under reduced aeration is cooled down with water. Temperature generated in the barrel could reach over 400°C when monitored. Research should be pursued to generate information on the locally improved ways of pyrolysis of available biomass, and the agronomic quality of biochar from different feedstocks, in different soils and for different crops, as this technology will quickly become profitable. The availability of such information will go a long way in finding a sustainable way in organic waste management, especially for farmers in Ghana who cannot afford the increasing cost of inorganic fertilizers.

Figure 8. Monitoring of temperature in a biochar production in Ghana (local method).

8.4. Biogas Production

Biogas is a clean and renewable form of energy that is produced through anaerobic digestion of organic waste. It can be produced from manure, sewage sludge, biodegradable fraction of municipal solid waste and various agricultural wastes. The biogas comprises primarily of methane and carbon dioxide. Arthur et al. (2011) reviewed the potential of biogas production in Ghana, and traced the historical antecedents of biogas plants in the country. The first biogas demonstration plants in Ghana were established between 1986 and 1987 near cattle ranches, with the aim of utilizing the cattle manure for energy production. Subsequent to that, the Ministry of Energy established the first major comprehensive biogas demonstration project in Ghana (the Integrated Rural Energy and Environmental Project) in 1990 at Apollonia, a village located some 46 km from Accra. The project utilized 10 hydraulic dome digesters, each of capacity 50 m^3. Both animal manure and human excreta were applied to generate 12.5 kW power for street and home lighting and cooking at Apollonia. The slurry by-product was then used for agriculture. The project was largely successful as it reduced a potential consumption of diesel by about 66% (Mensah, 2000). Other agricultural solid and liquid wastes such as citrus fruit waste, POME, sugar cane waste (bargasse) could be used as feedstock for biogas production for the rural communities. This could reduce the cost for electricity to the rural consumer and save electricity for manufacturing industries in the cities and urban centres.

9. Environmental Health Risks Associated with Contaminated Feedstock for Composting

It must also be emphasized that waste management methods such as composting may be associated with some environmental health risks. For instance, the compost could contain contaminants such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs), depending on the feedstock and the composting process. Heavy metals in compost usually are intrusions from contaminated materials in the compost feedstock, especially when the compost is prepared from mixed MSW. Compost produced from source separated organic waste has reduced content of heavy metals compared to those from un-segregated waste (Hogarh et al., 2008). Studies conducted in Ghana suggest that agricultural waste compost produced from mixtures of cocoa husk, chicken droppings and rice straw or saw dust contained less than 0.01 mg/kg of lead (Pb) and cadmium (Cd) (Hogarh et al., 2008). In the same study, it was realized that the contents of Pb and Cd in compost produced at household level were low, but Pb content of mixed MSW composts exceeded the Australian compost quality standard of 150 mg/kg (Environment Australia, 2003).

Persistent organic pollutants (POPs) such as PCBs are reportedly concentrated with composting. About 30% increase in low-chlorinated PCBs occurred during composting (Brändli et al., 2007). Composting of green waste generated relatively greater content of PCBs in the compost product (Brändli et al., 2005). It was presumed that concentration of the POPs might have increased with composting because of the reduction in composting volume. On the other hand, the concentration of PAHs seems to decrease with composting (Amir et al., 2005; Brändli et al., 2007). Hence, composting has been applied as a bioremediation process for treating particularly contamination from PAHs in soil and sewage sludge (Crawford et al., 1993; Cajthaml et al., 2002; Sayara et al., 2011).

Composts derived from crop residues and other agricultural wastes often contain relatively increased content of some pesticide residues. Among the categories of pesticides, organophosphates and carbamates were rarely detected upon composting of crop residue feedstock (Büyüksönmez et al., 2000). There are however conflicting reports on the behavior of OCP residues during composting. Büyüksönmez et al. (2000) suggested that OCPs were resistant to degradation during composting. Later findings however suggest the contrary and that OCPs may be degraded to some extent in a composting medium (Barker and Bryson, 2002; Hellström et al., 2011). Thus, although these recalcitrant pollutants could get into a composting medium via the feedstock, the composting process may double up as a bioremediation process that degrades these pollutants.

10. Building New Capacities and Strategies for Waste Management in Ghana

10.1. Tertiary Institution and Capacity Building to Manage MSW

The first university dedicated to the training of sanitation and waste management professionals in Ghana and West Africa has been officially opened in Ghana. Kwame

Nkrumah University of Science and Technology (KNUST)–Africa Institute of Sanitation and Waste Management is a collaboration between Zoomlion Ghana Limited, a waste management company, and the KNUST.

The Institute has begun diploma and certificate programmes in Sanitation Management and Environmental Sciences. The institution has since admitted students for the various programmes. The establishment of this institution will go a long way in developing homegrown technologies to manage MSW and also train the needed manpower to design homegrown solutions to address the challenge of municipal solid wastes management in Ghana.

10.2. Value Addition

In an attempt to address common challenges facing West African countries in waste management, experts from Ghana, Nigeria, Cote d'Ivoire and Senegal met at a waste management conference in Accra, Ghana in May, 2012. The aim of the conference was to develop a comprehensive plan that will help tackle challenges associated with solid waste management in the Western African countries. A consortium that will promote integrated solid waste management (ISWM) systems was to be established. The major priority of the consortium is to empower stakeholders participating in the waste management chain through the enforcement of legal framework and open transfer of knowledge and technology among the West African countries. Waste is regarded both as a negative and as a useful material providing a potential source of income to the unemployed under the ISWM system. The system involves the primary collection and recycling at community level while improving the health and environmental conditions of community dwellers.

The economic value in recycled products such as compost should be projected and appropriate markets identified when considering any waste recycling program. Producing a marketable product like compost and recovering revenues by selling the compost is usually a challenge in Ghana. Composting projects should be viewed as a commercial production process instead of purely an environmental process. Selling compost on the open market is essential to sustaining a composting program, but this would require that the compost meet high quality standards. In this regard, the type of feedstock for composting is critical, as it plays an important role in determining the final quality of the compost product. Municipal solid wastes (MSW) composts without source separation generally have low quality compared to agricultural waste composts (Hogarh et al., 2008). Adamtey et al. (2009) have improved the nutrient quality of low quality grade composts processed from MSW through and/or co-composting with dewatered human faecal sludge and inorganic nitrogen enrichment.

CONCLUSION

This study provided a quick review of waste management in Ghana with a greater focus on organic waste recycling and other recycling opportunities. The percentage of organic waste in the municipal solid waste stream in Ghana declined from 85% to 60% between 1994 and 2002. In the same period, the contents of plastic and paper, as well as those categorized as "others" increased. Notably, the "other" wastes, which could also be described as miscellaneous increased from 3% to 13% in almost a decade. This portends increased heterogeneity of the waste stream and calls for waste policy and strategy reforms to reflect these dynamics. Composting, biochar and biogas production were identified as the major opportunities available to managing the huge organic waste fraction in the waste stream in Ghana. With respect to the composting of municipal solid wastes, decentralized community composting appears more sustainable than large scale centralized composting. There are also opportunities for the recycling of plastic wastes. This review further identified that waste management in Ghana is beset with a myriad of challenges, which were categorized as policy, communal, technological and financial challenges.

The potential threats of waste management in Ghana mostly concern environmental contamination and risk of exposure to various environmental hazards. The major threats relate to the use of open dumpsites and non-engineered landfills as final disposal points of waste. These disposal sites contaminate the air, soil and nearby water resources, and are health threats to nearby residents and scavengers who visit these sites to collect recyclable items. Overall, there is great potential to harness materials in the waste stream in Ghana for various recycling ventures. This will help to divert useful materials from dumpsites and landfills in Ghana. It would however require overcoming specific policy, communal, technological and fiscal barriers identified in this review. Centralized composting has also been viewed as a potential intervention. In order to assess the viability and appropriateness of these large-scale and high technology projects, a number of considerations must first be evaluated, prior to planning and implementation. Decisions regarding the selection of waste management systems need to be determined based on the proposed system's appropriateness within specific localities, with all location-specific social, political and economic factors thoughtfully assessed and factored into the decision-making process. For instance, local capacity, potential stakeholders (i.e., Local communities, private-sector enterprises, government agencies), the physical layout of the city, municipal budgets and access to capital, and local waste characterization must also be determined (Oteng-Ababio, 2009).

The solid waste management system in Ghana, especially the major cities, is constrained by a lack of competent personnel with the requisite technical expertise for solid waste planning, operation and monitoring, and landfill design and operation. Many of the workers, particularly among the small-scale firms, have little or no training in waste management. For an effective and efficient solid waste management system, there is the need for the waste stream to be characterised by their sources, types, generation rates and composition. Accurate data on solid waste will enable effective monitoring, controlling existing waste systems, and also help in making regulatory, financial and institutional decisions. Unfortunately, the solid waste management system in Accra, does not have any database. Much of the available available data are based on estimates, which are in many cases unreliable. The lack of accurate data on solid waste generation and characteristics impedes any sustainable waste management programmes for the city.

The waste collection, transfer, separation, recycling and/or disposal activities of informal waste workers constitute economically valuable services. Informal waste workers work, normally, on a "self-employed" basis or as informally organized groups; in some cases they may be hired directly by households and/or neighbourhood groups. In general, however, the marginalized and unstable social and economic circumstances of informal waste workers make it quite difficult to integrate their contribution into the MSWM system. As an initial step, informal workers require organizational and technical support to promote their social rehabilitation and alleviate the unacceptable socio-economic conditions in which they live and work. Through the formation of co-operative societies or micro-enterprises, it is often possible to considerably increase the job stability and earnings of informal sector workers, and to enhance the effectiveness of their contribution to waste management.

Informal wastes collectors including waste pickers, waste recyclers, scavengers and waste carriers must be fully integrated into the waste management stream in order to realise the benefits of their contributions to environmental management in the city. Strategies for waste management in Ghana, must involve the active participation of those affected by solid waste problems, as well as those who control policies and implementation instruments, and those who possess relevant information and expertise. Involving communities in decision making will create communities' self-confidence for mobilising efforts and local resources for environmental management particularly in low income areas.

Also, more efforts must be directed at upgrading municipal solid waste management infrastructure and services. This must include the provision of adequate facilities for waste management and requiring users to pay for the full cost of the service in order to enhance the efficiency and coverage of service delivery).

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Chapter 2

ENVIRONMENTAL APPLICATIONS OF ENZYMES

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ABSTRACT

Enzyme operations fit into the two traditional treatment systems, namely chemical and biological because they involve chemical reactions founded on the actions of the organic catalysts. Various enzymes from plants and micro-organisms have been reported to play significant roles in many waste applications. Prior to the full potential of enzymes that can be achieved, a few significant issues remain to be solved (settled). These include, among others, the development of enzyme sources in amounts that are necessary for industrial scale at a low cost; the demonstration of the feasibility (possibility) of enzymes under conditions encountered in the sewage efficient treatment; the wastewater characterization of the reaction products and assessment of their impact on downstream processes or on the environment within which they are released and finally the identification approaches for solid residues evacuation.

Keywords: Enzyme technology, waste management, environment impact

1. INTRODUCTION

Extensive research and development work have has been conducted in recent years to enable industrial, municipal and commercial facilities to reduce their impacts on the environment. In particular, the implementation of increasingly stringent standards for the discharge of wastes into the environment has necessitated the need for the development of alternative processes for the production of goods and for the treatment and disposal of wastes. Ultimately, the objectives of these processes are: (1) to improve the efficiency of utilization of raw materials, thereby conserving resources and reducing costs, (2) to recycle waste

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streams within a given facility to minimize the need for effluent disposal, (3) to reduce the quantity and maximize the quality of effluent waste streams (air, water, and solids) that are created during production of goods, and (4) to transform the waste compounds into materials that may be recovered as fuels or that can be used in the production of new goods. These methods all fall under the environmental strategy represented by the widely accepted hierarchy of the 4R's:i.e, Reduce, Reuse, Recycle and Recover. There is a multitude of ways in which the transformation of process components and waste streams can be carried out. Most of these methods may be classified as being chemical and biological in nature (Aitken, 1993).

Chemical transformations involve the application of reagents and reaction conditions to chemically alter species through a chain of events resulting in the yield of a desired product. Such processes often require the presence of excess quantities of reagents to accomplish the transformation to the desired extent. In addition, particularly harsh conditions (e.g., high temperature or extremes of pH) are often required in order to facilitate the chemical transformations. Finally, many chemical treatment processes are not highly selective in terms of the types of pollutants that are transformed during treatment (Aitken, 1993).

Biological processes are designed to take advantage of the biochemical reactions that are carried out in living cells. Such process makes the use of the natural metabolism of cells to accomplish the transformation or production of chemical species. They can be conducted without the harsh conditions that are necessary during chemical transformations. However, due to the sensitivity of microorganisms to changes in their environment (e.g., salinity, temperature, pH and presence of toxic or inhibitory compounds), these processes can be difficult to control over the long term, and may be subject to frequent upsets. They also require a supply of macro and micronutrients for the support of microorganisms growth, and often result in the formation of large quantities of biomass that ultimately must be discarded into the environment (Aitken, 1993).

A recent research has focused on the environmental applications of pure enzymes that have been isolated from their parent organisms. The reasons for this recent interest are fourfold: (1) the rate of introduction of recalcitrant organic pollutants into the environment is on the rise, and it is becoming increasingly difficult to achieve an acceptable degree of removal of these pollutants using conventional chemical and biological processes, (2) there is a need for the development of alternative treatment methods that are faster, cheaper, more reliable, and simpler to implement than current processes, (3) there is a growing recognition that enzymes can be used to target specific pollutants for treatment, and (4) recent biotechnological advances are expected to enable the production of cheaper and more readily available enzymes through genetic manipulation of microbial and plant cells through improved efficiency of isolation and purification procedures (Aitken, 1993).

The objectives of this chapter are: (1) to provide an introduction to enzymes and their advantages, and (2) to summarize some of their environmental applications.

2. ENZYMES

Enzymes are classes of proteins that catalyze specific reactions in biological systems. They are present in all living cells, where they perform a multitude of vital functions ranging from cell signaling to metabolic processes. Acting as catalysts, enzymes speed up chemical processes without being consumed in the process and so, in principle, they could catalyze reactions indefinitely.

Table 1. Enzyme market segments and applications (Headon and Walsh, 1994)

Applications	Uses
Detergent industry	• Degradation of protein, starch, and fatty stains in laundry • Color clarification and softening of cotton laundry • Automatic dishwashing • Surfactant production
Textile Industry	Polishing cotton fabrics • Stonewashing denim garments • Degumming silk • Bleach cleanup • Removal of starch from woven materials • Starch Industry • Production of dextrose, fructose, and special syrups for the baking, confectionery and soft drink industries, among others
Starch Industry	• Production of dextrose, fructose, and special syrups for the baking, confectionery and soft drink industries, among others
Baking industry	Degradation of starch, proteins and glucans when brewing with a combination of malt and unmalted raw materials, e.g., barley, corn and rice
Wine and juice industry	• Degradation of pectin when manufacturing fruit juices, wine, etc.
Alcohol industry	• Degradation of starch into sugars which are converted to alcohol through fermentation
Food functionality industry	• Improvement of nutritional and functional properties of animal and vegetable proteins • Process of optimization, e.g., energy savings by lowering of viscosity
Dairy industry	• Curdling of milk • Conversion of lactose in milk and whey into sweeter, more easily digestible sugars • Flavor development in specialty cheeses
Personal care industry	• Biotechnological ingredients for personal care products
Pulp and paper industry	• Control of pitch problems caused the use of mechanical pulps • Reduction of chlorine consumption in pulp bleaching process • Viscosity control in starch-based Coatings
Leather industry	• Soaking of hides and skins, unhairing, bating and defatting
Fats and oils industry	• Modifications of fats and lecithins, and synthesis of esters
Biocatalysis	• Synthesis of organic compounds

In practice, however, because enzymes are protein molecules, they have a half-life. Thus, most organic catalysts have a limited stability and break down over time, exhibiting decreasing activity. Besides rate of activity, enzyme efficacy characteristics such as optimal pH and temperature vary widely (Uhlig, 1998).

There are several categories of enzymes. Oxidoreductases catalyze the transfer of reducing agents from one substrate to the other. Transferases initiate the transfer of a functional molecular group from one substrate to another. Isomerases mediate the rearrangement of chemical bonds within a substrate. Ligases or synthetases initiate the joining of two molecules, hydrolyzing a nucleoside triphosphate in the process. Hydrolases catalyze the hydrolysis of a substrate, and lyases help cleave a bond by means other than hydrolysis. Common examples of the latter two include proteases which degrade proteins into its constituent amino acids, lipases that cleave fats into glycerol and lipids, and a variety of hydrolases that break down complex carbohydrates into sugars. Cellulases fall into the final category. Enzymes are harvested from a variety of sources. Although most commercial enzymes are microbially derived, a significant number of enzymes also are derived from plant and animal sources (Walsh and Headon, 1994). Microorganisms represent an attractive source of enzymes because they can be cultured in large quantities in a relatively short time period by established methods, and as such they can produce an abundant, regular supply of desired enzyme products. Moreover, microbial proteins are often more stable than enzymes of similar specificity obtained from plant or animal sources and often may be stored under less than ideal conditions for weeks without significant loss of biological activity (Headon and Walsh, 1994). Once extracted from the bacterium or fungus and purified, the cell-free enzyme may be used industrially. Isolated enzymes are often used in commercial processes that were previously either mechanical or cellular. Although antibiotic and brewing fermentation are the most recognized industrial uses for enzymes, the number of potential and realized applications continues to grow. In denim softening procedures, physical “stonewashing”, which mechanically cleaves the fibers that lie perpendicular to the fabric has been replaced with a commercial cellulase digestion which hydrolyzes the fibers enzymatically. Enzymes are also used in increasing numbers as a replacement for processes that traditionally employ live microbial cells. Cell-free enzymes have been used to degrade carbohydrates in the baking industry and proteins in the leather industry. These industrial enzymes have great potential for the treatment of environmental contaminants as well as general waste treatment (Nannipieri and Bollag, 1991) as seen in Tables 1 and 2.

Table 2. Enzymes contributing to sustainable industrial development (Headon and Walsh, 1994)

Industry segment	Enzymes	Chemicals/Process replaced
Detergents	Lipases, proteases, cellulases, amylases	Phosphates, silicates, high temperatures
Textile	Amylases, cellulases, catalases	Acid, alkali, oxidizing agents, reducing agents, water, pumice, energy, new garment manfacture
Starch	Amylase, pullulanases	Acids, high temperatures
Baking	Amylases, proteases, xylanases	Emulsifying agents, sodium bisulfate
Pulp and Paper	Xylanases, mannanases	Chlorine, toxic waste
Leather	Proteases, lipases	Sulfides, high temperature
Biocatalysis	Isomerases, lipases, reductases, acylases	Acids, organic solvents, high temperatures

3. ENZYMATIC PROCESSES ADVANTAGES

Enzymatic systems fall between the two traditional categories of chemical and biological processes, since they involve chemical reactions based on the action of biological catalysts. Specifically, enzymes are biological catalysts that regulate the multitude of chemical reactions that occur in a living cell, whether it be plant, animal or microbial. They carry out such cellular processes as energy conversion, food digestion and biosynthesis. Enzymes that have been isolated from their parent organisms are often preferred over intact organisms containing the enzyme because the isolated enzymes act with greater specificity, their activity can be better standardized, they are easier to handle and store, and enzyme concentration is not dependant on bacterial growth rates (Ahuja et al., 2004).

This can lead to some important advantages of enzymatic processes over biological systems such as: their applications to compounds that resist biodegradation, their high selectivity allowing for the treatment of targeted pollutants, their action on, or in the presence of many substances which are toxic to microbes, their operation over relatively wide temperature, pH and salinity ranges compared to cultures of microorganism, their operation both at high and low concentrations of contaminants, their high reaction rate compared to biological processes which enables the use of smaller systems of lower cost; the absence of shock loading effects associated with changes in contaminant concentrations that overwhelm the microorganism's ability to adapt, the absence of delays associated with shutdown/startup periods that are normally required to acclimatize biomass to waste streams; the lower quantity of sludge production since biomass is not generated, and a high system stability allowing for simpler process control (Ahuja et al., 2004).

Enzymes can also offer a number of advantages over conventional chemical processes. Such advantages include: a high degree of specificity that allows enzymes to remove target pollutants selectivity, which precludes undesirable or unnecessary reactions which would otherwise increase reactant consumption and, correspondingly, increase the cost of treatment; operation on compounds that are present in trace quantities (i.e., micropollutants) or that cannot removed by existing chemical/physical processes, operation in a catalytic manner resulting in a high reaction velocity and efficient use of chemical reagents; operation under low temperature conditions, thereby reducing energy requirements for processes normally conducted at elevated temperatures, and operation under mild pH conditions, thereby reducing the impact of corrosion on reaction vessels and avoiding the need for waste neutralization (Ahuja et al., 2004).

While the above advantages are indeed significant, it should be noted that the majority of chemical and biological processes are not candidates for replacement by enzymatic processes. That is, biological processes and some chemical processes (e.g., oxidation) have a fundamental advantage over enzymatic systems: i.e., their ability to simultaneously transform a broad range of compounds. For example, many municipal, agricultural, and industrial wastes consist of a mixture of organic compounds usually classified under the broad categories of biological oxygen demand (BOD) or chemical oxygen demand (COD). Once released into receiving waste bodies, these collections of organic compounds result in the depletion of dissolved oxygen in the water column as a result of natural microbial processes. In many instances, the majority of these compounds can be efficiently degraded through the combined action of mixtures cultures of microorganisms. In contrast, enzymes are biological catalysts whose actions are tailored to exclusively act upon specific chemical species. Thus, enzymatic treatment will not result in the removal of a broad range of compounds from a waste stream, but will not accomplish the transformation of an individual compound or class of compounds. This limits the application of enzymes to accomplish the transformation of the target species that are either problematic due to their toxicity or that have been identified as the raw materials from which enzymes can produce value-added products (Ahuja et al., 2004).

4. Potential Applications of Enzymes

Some potential applications of enzymes include the transformation of solid wastes, cyanide wastes, Organophosphates substances (OPS), phenols and aromatic amines, heavy metals, dyes, surfactants, food processing wastes and cellulosic wastes. These applications are described below.

Solid Wastes

Enzymes have also been used to improve the dewatering of sludges that are produced as a byproduct of waste water treatment. Anazia and Misra (1989) reported that peroxidase treatment of phosphatic slimes which contain considering amounts of swelling clay like material induced a higher mechanical binding among slime particles and that peroxidase significantly promoted the growth of algae and mold with the beneficial effect of enhanced aggregation of the particles. Hakulinen (1988) reported on the use of cellulose and the bacterial enzyme, lysozyme, for sludge dewatering.

Roman et al. (2006) used commercially enzymes in solubilising the organic, bacterially undegraded component of digested sludge solids. The enzymes used were cellulase, pronase E, and a combination of both. These enzymes were chosen to target the undegraded toilet tissue paper, protein and dietary fiber (mainly cellulose) components of primary sludge dry solids. It was found that the mixture of the two enzymes resulted in an 80% reduction in solids (cf. 20% in the control), 93% removal of particulate chemical oxygen demand (COD) (59% in the control) and 97% total COD removal (vs. 63%). The total suspended solids (TSS) concentration was reduced by 80%, from 25 g/l to 5 g/l. Single enzymes had little or no impact on sludge solubilisation, and final COD and TSS, but all of the enzyme additions were seen to decrease the production of volatile fatty acids (VFAs). Since accumulation of VFAs can lead to digester failure, it was concluded that the enzyme additives enhanced digester performance in terms of degradation of COD, reduction in sludge solids remaining after digestion and improved digester stability owing to the stable prevailing pH. The results indicate that enzyme addition at full scale could be expected to lead to greater methane yields, lower strength sludge liquors and a significant reduction in the requirements for and costs of digested sludge dewatering and disposal.

Cyanide Wastes

Cyanide is a triple-bonded molecule with a single negative charge consisting of one atom of carbon in the +2 oxidation state and one atom of nitrogen in the -3 oxidation state. The immensity of cyanide amount in the environment is mainly due to metal finishing and mining industries. Although cyanide can be removed and recovered by several processes, it is still usually discussed and examined due to its potential toxicity and environmental impact (Das et al., 2009). The chemical speciation of cyanides depends on their sources and also in response to a variety of environmental factors. Different forms of cyanide include: free cyanide, cyanide ion, cyanide salt, metallocyanide complexes and synthetic organocyanides, also known as nitriles and total cyanide (Eisler, 1991). Cyanide occurs in water as hydrocyanic acid (HCN), cyanide ion (CN^-), simple cyanides, metallocyanide complexes and as simple chain and complex ring compounds. Simple cyanides include water soluble salts of alkaline earth, alkali and heavy metals. Typical simple cyanides are NaCN, KCN, $Ca(CN)_2$, $Hg(CN)_2$, $Zn(CN)_2$, $Cd(CN)_2$, $Ni(CN)_2$ and Ag CN. The simple cyanides such as potassium cyanide and sodium cyanide ionize in water to release a cation and cyanide ion (Eisler, 1991). Metallocyanide complexes have a wide range of stabilities. Zinc [Zn (CN) 4^{-2}], cadmium [Cd (CN) 3^{-2}] and Cd (CN) 4^{-2}] complexes dissociate rapidly and nearly completely in dilute solutions (US EPA, 1985). Nitriles are organic compounds (R-CN) containing the cyanide group (CN). Cyanide bound to carbon as nitriles (other than as cyanogenic glycosides) is comparatively innocuous in the environment, low in chemical reactivity and is biodegradable (Eisler, 1991). Cyanide and chemically related compounds are formed, excreted and degraded in nature by hundreds of species of bacteria, algae, fungi, plants and insects (Knowles, 1976). As a result, low levels of cyanide can appear in naturally occurring surface or groundwater samples which normally would not be expected to contain it. At least 1,000 species of plants and micro-organisms from 90 families have been shown to contain one or more of nearly twenty compounds capable of producing cyanide (Seigler, 1976). About 800 species of higher plants from 70 to 80 families, including agriculturally important species such as the cassava, flax, sorghum, alfalfa, bamboo, peach, pear, cherry, plum, corn, potato, cotton, almond and beans are cyanogenic (Eyjolfsson, 1970). Cyanide is fast-acting broad spectrum toxin and it affects all living organisms. Cyanide ion exerts an inhibitory action on certain metabolic enzyme systems, most notably cytochrome oxidase, the enzyme involved in the ultimate transfer of electrons to molecular oxygen. In the presence of even weak acids, HCN gas is liberated from cyanide salts (Smith and Mudder, 1991). Cyanide poisoning can occur through inhalation, ingestion and skin or eye contact. One teaspoon of a 2% solution can kill a person. In general, fish and other aquatic life are killed by cyanide concentrations in the *microgram per liter* range (part per billion), whereas bird and mammal deaths result from cyanide concentrations in the *milligram per liter* range (part per million). The release of cyanide from industries worldwide, has been estimated to be more than 14 million kg/yr (Ebbs, 2004). Industries concerned with the production and use of cyanide compounds generate wastes which contain large amounts of cyanide. Especially paint manufacture and use, polymer production, chemical and pharmaceutical industry, steel industry, mining operations and coal manufacturing all produce waste and waste water with high cyanide content. Electroplating industrial wastes contain 0.5% to 20% cyanide. Complex cyanide, Prussian blue is used for dyeing jeans. Since, cyanide is a toxic compound well-known as a metabolic inhibitor, cyanide-containing effluents cannot be discharged without being subjected to treatment to reduce their cyanide contents to very low levels (>0.1 mg of CN^- per liter) (Smith and Mudder, 1991). US-health service cites 0.01mg/L as guideline and 0.2 mg/L as the permissible limit for cyanide in effluent (Das et al., 2006).

Cyanidase is an enzyme preparation capable of converting cyanide in industrial waste waters to ammonia and formate in what appears to be a single step reaction (Basheer et al., 1993). Cyanidase is based on certain gram negative bacteria isolates from the genus *Alcaligenes denitrificans* and it is prepared by proprietary methods. It is characterized by a high affinity and a high stability toward cyanide and is able to remove the latter down to very levels, i.e.‹ 0.02 mg/L CN^- (Basheer et al., 1992). Cyanidase activity was neither affected by the common ions normally present in waste waters (e.g., Fe^{2+}, Zn^{2+} and Ni^{2+}), nor by organic substrates such as acetate, formamide, acetamide and acetonitrile. In a study done on the detoxification by cyanidase of a cyanide-containing extract from debittering apricot seeds in the food industry. Basheer et al. (1993) developed a diffusional type flat membrane reactor (FMR) and noted its superior performance relative to stirred tank reactor and fixed bed reactor configurations. The advantages of an FMR include the protection of the enzyme from interfering particles and large molecules to avoid attrition and shear damage to the immobilization support. Cyanide diffuses through a semi permeable membrane to react with the entrapped enzyme behind the membrane and reaction products diffuse back across the membrane to the solution.

Cyanide hydratase, also known as formamide hydrolyase, has been reported to hydrolyze cyanide to formamide (Basheer et al., 1993), (Nazly et al., 1993). Cyanide hydratase is produced by a variety of fungi and is inductible upon preexposure of the fungi to low concentrations of cyanide. Nazly et al. (1993) noted that cyanide hydratase was more stable when immobilized and that the enzyme from *Gleocercospora sorghi* was much more stable than that from *Stemphylium loti.* They concluded that immobilized fungal cyanide hydratase is suited for the treatment of industrial effluents containing cyanide.

Organophosphates Substances (OPS)

OPs are toxic substances that are used in herbicides and pesticides. The potential adverse effects that the pesticide and insecticide industry can have on the environment arise from the disposal of wastes formed during their production and formulation, detoxification of their containers and spray tanks and the pollution of surface and groundwater by their runoff (Munnecke, 1978). Qiao et al. (2003) developed a genetically engineered form of carboxylesterase that will degrade and detoxify the OP wastes malathion, parathion, and monocrotophos. The enzyme degraded about 80% of the malathion in 90 min, about 85% of the parathion in 6 h and about 20% of the monocrotophos in 9 h. The reason why malathion and parathion degraded faster and more completely than monocrotophos is that these two compounds contain carboxylester bonds, which are readily broken down by a carboxylesterase, while the other compound does not. These contact times appear to be quite feasible for a field implementation. Zhang et al. (2004) also studied the impact of a recombinant carboxylesterase derived from an insecticide-resistant mosquito on OPs. They discovered that 0.1 nmol of the enzyme was able to neutralize 1 nmol of chlorpyrifos and 2 nmol of paraoxon individually.

Laccase derived from *Phanerochaete chrysosporium and Trametes versicolor,* as well as purified laccase were found to be able to inactivate the herbicide diketonitrile by converting it into a benzoic acid analogue. The purified laccase requires the presence of 2 mM 2,2'-azinobis (3-ethyl-henzthiazoline-6-sulfonic acid) and at a temperature of 30-50°C and a pH of 3 in order for this reaction to occur (Mougin et al., 2000). Such extreme conditions are not feasible for field implementation, but this study is able to illustrate that laccase can catalyze the degradation of diketonitrile, which further demonstrates its versatility.

Phenols and Aromatic Amines

Phenols and aromatic amines are the most important classes of synthetic chemicals and are often present in the industrial chemicals and are often present in the industrial effluents from various manufacturing operations. Numerous chemical industries, sending these toxic chemicals in the environment, are: coal conversion, petroleum refining, resin and plastic, dyes and other organic chemicals, textile, timber, mining and dressing, pulp and paper. In addition, among the different classes of pollutants, those that enter the environment, some of them are also derived from agricultural activities. Large scale use of herbicides, insecticides and pesticides in agriculture contributes to the presence of these hazardous materials in the surface and in the ground water. Phenols and aromatic amines are also released as intermediary products during the microbial degradation of pesticides or some other xenobiotics. The vast majority of phenols has been classified as toxicity priority carcinogens. The pollutants such as phenols and aromatic amines play an important role in the ecological balance of some of the compartments of soil and water. The presence of these chemicals in ground water or in drinking water poses a significant health risk. Therefore, the decontamination of these molecules from an industrial aqueous effluent is an important practical aspect prior to their final discharge (Qayyum and Ulfat, 2000).

In early 1980's, researchers first time developed an idea of using oxido–reductive enzymes for treating waste water containing these toxic chemicals. Some workers suggested that enzymes could be used to oxidize phenols to free radicals or to quinines and benzoquinoneimine. These oxidation products can couple to each other, resulting in the formation of water insoluble oligomers or polymers. These insoluble complexes are less toxic as compared to their soluble substrates and can be easily removed from the reaction mixture by simple filtration or sedimentation or centrifugation. A wide spectrum of oxidoreductases enzymes from different sources have been considered for these studies, such as peroxidases, laccases and tyrosinases (Qayyum and Ulfat, 2000) (Table 3).

Peroxidase enzymes are produced in the cells of many microorganisms and plants. They catalyze a variety of reactions, but all require the presence of oxidants such as hydrogen peroxide to activate them. Hydrogen peroxide first oxidizes the enzyme, which in turn oxidizes the substrate. The reaction products are subsequently polymerized through a non-enzymatic process leading to the formation of water insoluble precipitates that can be removed from the aqueous phase by sedimentation or filtration. Peroxidases have been used for the laboratory scale treatment of aqueous aromatic contaminants include horseradish peroxidase, soybean peroxidase, chloroperoxidase, manganese peroxidase and lignin peroxidase. Of these, horseradish peroxidase (HRP) is undoubtedly one of the most studied enzymes in the relatively new area of enzymatic waste treatment. It is particularly suitable for waste water treatment because it retains its activity over a broad range of pH and temperature (Qayyum and Ulfat, 2000).

Table 3. Enzymes used in the toxification of phenols and aromatic amines (Qayyum and Ulfat, 2000)

Enzymes	Source
Chloroperoxidase	*Calariomyces fumago*
Laccase	*Trametes versicolor* *Coriolus versicolor*
Lignin peroxidase	*Chrysonilica sitophila* *Phanarochaete crysosphorium*
Manganese peroxidase	*Lentinula edodes*
Peroxidase	*Armoracia rusticana (Horseradish)* *Caprinus cinereas* *Caprinus macrrohizus* *Raphanus sativus (White radish)* *Brassica rapa (Turnip)*
Tyrosinase	*Agaricus bispora (Mushrooms)* *Solanum tuberosum (Potato)*

The major problem in the development of peroxidase based catalysis for industrial applications is the susceptibility of the enzyme to inactivation, which is caused by adsorption of enzyme molecules on the final product of reaction. Some researchers have reported the addition of certain adsorbents in the reaction mixture to prevent the inactivation of peroxidase during the catalytic cycle. These additives adsorb the product of reaction and thus prevent the loss of enzyme activity.

Laccase and tyrosinase require molecular oxygen for the formation of oligomeric or polymeric phenols. Laccase can be easily isolated from the culture medium of *Coriolus versicolor* and it can act on a broad range of substituted phenols. Laccase is capable of cross coupling toxic molecules with naturally occurring phenols like syringic acid and vanillic acids and converts them into humic like polymers. In an aerated liquid medium laccase can polymerize successfully lignosulphonates from spent sulphite effluents (Rao et al., 2010).

The use of tyrosinase was proposed as a cheaper alternative to HRP because it uses molecular oxygen as an oxidant instead of expensive hydrogen peroxide. The cost of the laccase isolation from microbial sources is also a hurdle in the use of enzymes for the decontamination of various waste waters. An easy availability of tyrosinase and utilization of free oxygen as an oxidant, will definitely reduce the cost of phenols and aromatic amines detoxification from industrial waste waters.

Recently, chitosan has been used as a suitable adsorbent during the tyrosinase catalyzed reaction. Chitosan is a polysaccharide and obtained from waste material of shellfish industry. This polymer contains amino groups which specifically binds to benzoquinone molecules and form insoluble aggregate which can be easily removed by centrifugation or filtration.

In addition to mushroom tyrosinase, other plant sources should be evaluated for the decontamination potential because polyphenol oxidases do not require the addition of expensive hydrogen peroxide. The major reasons that enzymatic treatments have not been applied on an industrial scale are due to the huge volume of polluted environments demanding bioremediation. For instance, hundreds of thousands of liters of waste water are produced daily from an average industrial site and hundreds of tons of soil may be contaminated through continuous industrial emission or through a single spill accident. Use of soluble enzyme is practically impossible for determination of such as an extensive contamination. The applications of soluble enzymes also suffers from certain drawbacks such as thermal stability, susceptibility to attack by proteases, activity inhibition and the lack of know-how for separating and reusing free catalyst at the end of the reaction. Another important disadvantage is that the free enzyme cannot be used in continuous process (Nannipieri and Bollag, 1991).

Heavy Metals

Heavy metals such as arsenic, copper, cadmium, lead and chromium, among others, are found in a number of industrial and mining waste streams as well as in solid wastes, municipal sewage sludges and landfill leachate (Pradham and Levine, 1992).

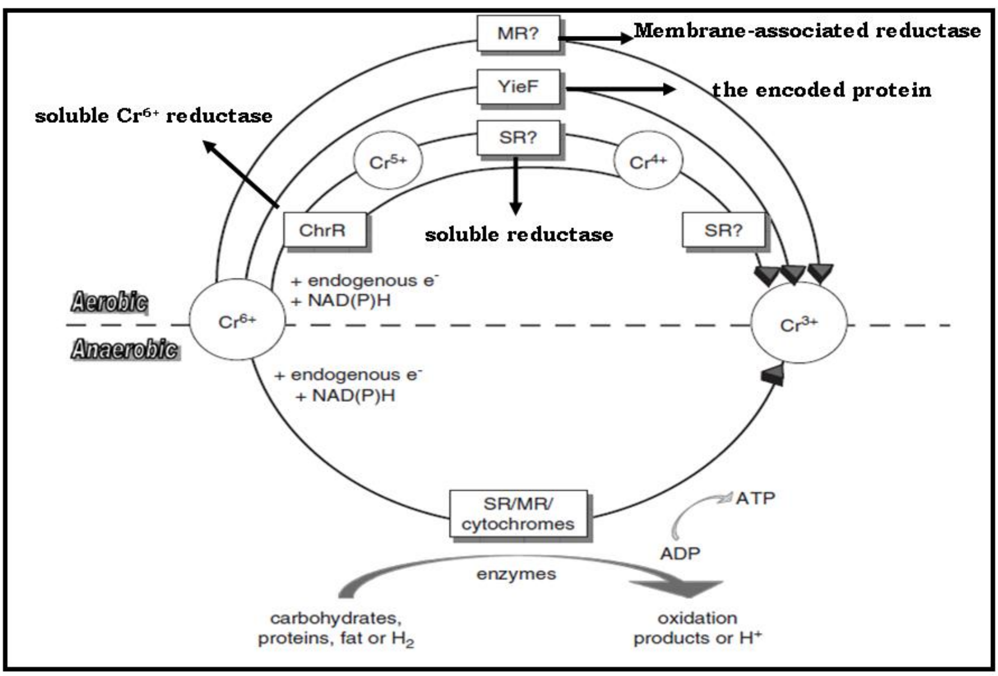

Figure 1. Mechanisms of enzymatic Cr^{6+} reduction under aerobic (upper) and anaerobic (lower) conditions (Cheung and Gu, 2007).

They are very often essential trace elements for living organisms. However, when present in the environment at high levels they may produce environmental and health problems because of their high toxicity. For instance, this is the case of chromium (Cheung and Gu, 2007), this element is widely used in several industries and its hexavalent species (Cr^{6+}) is a toxic, mutagenic and carcinogenic chemical. It is highly soluble, hence mobile and biologically available in the ecosystems. US EPA has identified Cr^{6+} as one of the 17 chemicals posing the greatest threat to humans. By contrast, its reduced trivalent form (Cr^{3+}) is much less toxic and insoluble.

Microorganisms possess enzymes capable of effectively reducing Cr^{6+} to Cr^{3+} under both aerobic and anaerobic conditions (Figure 1). Cr^{6+} reductases, ChrR and YieF, two soluble enzymes, have been recently purified from *Pseudomonas putida* MK1 and *Escherichia coli*, respectively.

These two enzymes are a promising alternative approach for bioremediation of chromium six in several environments, provided that their direct application can be afforded possibly as immobilized enzymes.

Macaskie and Declaimed that removal of cadmium, lead, copper, uranium and strontium from industrial wastes was thus successfully achieved. The process involves the use of *Citrobacter* sp. Cells immobilizied in polyacrylamide gel, through which metal containing solutions are passed. A cell bound phosphatase enzyme, induced during pre-growth by providing the substrate glycerol 2-phosphate as a sole phosphorus source, liberating inorganic phosphate in excess of that needed for growth. The latter, in turn, combines with the metal to form an insoluble metal phosphate at the cell surface. It was reported that more than 90% metal removal was observed and that the metal could be recovered from the immobilized cells that could be reused. Macaskie et al. (1987) demonstrated that the use of an enzyme called alcalase to treat and recover the chromium from chrome shavings that are important waste of tannery industries. The treatment reduced the chromium concentration in the wastes from a starting concentration of 26.6 g/kg to a final concentration of 4 mg/kg.

Dyes

Synthetic dyes are preferred for use over natural dyes due to their superior performance. As compared to natural dyes, synthetic dyes impart brighter colors, show better light-fastness and are more resistant to washing. Also, synthetic dyes offer a wider variety of colors. Wastewater or effluents from industries that manufacture paints, pigments and color cosmetics contain a variety of synthetic dyes. Industries involved in dyeing of textile, paper, leather and plastics, release effluents that are highly colored (Abo-Farah, 2010). Azo dyes feature among the most widely used synthetic dyes in the industry. Globally, the fixation of azo dyes (on textile) is quite low and often, up to 50% of the applied dye may be lost in the wash stream (Zille et al., 2004). The presence of dyestuffs in industrial effluent is more than just an aesthetic problem. The chromophores of dyes strongly absorb sunlight (Abo-Farah, 2010). When the effluent reaches the receiving water body, the dyes hinder photosynthesis by the aquatic flora. The presence of dyes in the water body increases the Chemical and Biological Oxygen Demand (COD and BOD respectively). Additionally, effluent containing dyestuffs are found to have a large concentration of suspended solids (Abedin, 2008). These factors upset the ecological balance of the receiving water body. Several dyes have been found to be potentially toxic (Zille et al., 2004). Thus, the presence of synthetic dyes is a serious environmental concern. Evidently, it is necessary to remove colorants from the effluent before it is discharged into a water body.

The removal of coloring matter from effluent is a major problem faced by industries. In general, the chemical structure of dyes contains conjugated double bonds and aromatic rings

(Zille et al., 2005). Many synthetic dyes tend to persist in the environment due to the inherent stability of their molecular structure. Azo dyes, for example, have a characteristic azo (-N=N-) linkage, which is an electron withdrawing in nature. The presence of this linkage decreases the susceptibility of azo dyes to oxidative reactions (Maddhinni et al., 2006) thus making them resistant to conventional degradation methods. Complex pollutants that resist degradation and tend to persist in the environment for long durations are considered to be recalcitrant pollutants (Mohapatra, 2006). Recalcitrance of a given pollutant may sometimes be attributed to unusual substitutions with halides (Cl^- or Br^-), very large molecular size, and the presence of unusual bonds or highly condensed aromatic rings. The presence of tertiary and quaternary carbon atoms also contributes to recalcitrance (Jogdand, 2006).

In order for dyes to be degraded in a wastewater treatment plant, the chromophores in the dyes must he oxidized and cleaved (Kandelbauer et al., 2004). Two enzymes, laccase and manganese peroxidase (MnP), are proven to be quite effective in this function. Laccase produced by *Pycnoporus snnguineus* in liquid cultures can completely decolor bromophenol blue and malachite green (both triphenylmethane dyes) and partially decolor orange G and amaranth (both azo dyes). lmmobilization of the enzyme on alumina increased its thermal stability and made it less affected by inhibitors, such as halides and dye additives. lmmobilized laccase was also able to decrease the toxicity of the dyes by up to 80% (Mayer and Staples, 2002). Furthermore, laccases from a variety of parent fungi, including *Trametes versicolor, Trametes hirsute, Pleurotlls ostreatus* and *Phlebia tremello.va.* have been found to be effective decolorizers for a wide variety of structurally different dyes (Kandelbauer et al., 2004). Also, it has been found that laccase from *Polyporus rubidus* is very effective in decolorizing of higher concentration of several dyes such as Reactive blue, Reactive orange, Ramazol black and Congo red along with effluents from textile units (Poonam and Debjani, 2008). In a recent study, the decolourization of synthetic textile dyes was made by using immobilized laccase enzyme alginate encapsulated beads isolated from white rot fungus *Pleurotus ostreatus* (Velu et al., 2011).

MnP proved highly effective at reducing dyes as well. The amount of decolorization was done by comparing the dye's absorbance before the enzyme was added and 7 days after the enzyme was added. MnP in a stationary culture was able to decolor approximately 85% of the Reactive Orange 16 dye and 99.7% of the Remazol Brilliant Blue R dye in that time period. In a submerged culture with 1 g/L of the inorganic surfactant Tween 80 added, MnP was able to decolor approximately 87% of the Reactive Orange 16 dye and 100% of the Remazol Brilliant Blue R dye. Significant decolorization was also shown in the addition of MnP to Drimaren Blue, Acid Black, and Drimaren Red in a polyurethane foam reactor (Novolny et al., 2011).

Surfactants

Surfactants or "surface active" agents are organic substances that have rather large polar molecules and are basic ingredients of detergents. They may cause significant pollution problems when high concentrations from shampoo formulation factories, for instance, enter municipal sewerage systems and generate undesirable conditions such as foaming (Thomas and White, 1991). Thomas and White (1991) reported that immobilized alkylsulfatase from Pseudomonas C12B could efficiently degrade surfactants up to a concentration of 750 mg/L.

The enzyme, which was observed to be specific to primary alkyl sulfates, was able to completely degrade alkyl sulfate and alkyl ethoxy sulfate surfactants in pure and commercial forms and had some effect on April sulfonates. However, the enzyme was practically incapable of attacking alkane sulfonates. Overall, alkylsulfatase showed promise for future use in the treatment of a range of surfactants found in shampoo formulation waste streams.

Food Processing Wastes

The food processing industry produces extremely large quantities of wastes. However, whereas the wastes generated by other industries are generally deleterious and must be rendered innocuous by appropriate treatment schemes, food wastes have the advantage of being amenable to conversion into food, feed or non food products with added value. Enzymes could be used to decrease food wastes via enzymatic processing to yield higher value byproducts (Shoemaker, 1986). Pectinesterase from *Clostrium thermosulfurogenes* and pectin lyase from *Clostrium beijerinckii* has been reported to degrade pectin, which is a water soluble substance that binds adjacent cell walls in plants. It has been shown that apple pomace can be degraded using pectineesterase to yield butanol. L-galactonolactone oxidase, from the yeast *Candida norvegensis* can be used to bioconvert galactose resulting from the hydrolysis of the lactose contained in whey to L-ascorbic acid which is a valuable commodity chemical (Shoemaker, 1986). Lactases have also been used in dairy wastes processing, mainly to produce value added products (whey protein concentrate) (Blasheck, 1992). Bioconversion of chitin to yeast single cell protein by using chitinases has been reported as an alternative of the disposal of shellfish wastes that have high chitin contents.

Shoemaker (1986) reported that amylases could be used to produce alcohol from rice processing wastes. Coleman (1990) reported a very interesting application of α amylase and glucoamylase enzymes in the production of photodegradable and biodegradable plastics.

Proteases are widely used in the food industry in processing fish and meat wastes. They can solubilize proteins in waste streams, resulting in recoverable liquid concentrates or dry solids of nutritional value for fish or livestock (Shoemaker, 1986).

Dalev (1994) reported the use of alkaline protease from *Bacillus subtilis* in the processing of waste feathers from poultry slaughterhouses. The end product of this treatment could be used mainly as feed constituent.

Cellulosic Wastes

For the past decade, there has been an increasing interest in the enzymatic hydrolysis of cellulose, a major component of paper (Clanet et al., 1998). This interest stems from the advantages that such a process would offer, namely, the conversion of lignocellulosic and cellulosic wastes to a useful energy source through the production of sugars, ethanol, biogas or other energetic end products (Coughlan, 1992). Clanet et al. (1998) have used cellulases from *Trichoderma reesei* CL847, *Penicillium starin* CLD20 and the thermophilic fungus CL240 to obtain hydrolysates from the organic fraction of municipal solid wastes that would be directly used as base for fermentation media. Sugar concentrates as high as 45 g/L were produced in a packed column reactor and the hydrolysates obtained could reportedly be used in anaerobic fermentation such as acetone-butanol or organic acid production.

Duff et al. (1994) performed studies investigating the possibility of hydrolyzing the highly cellulosic sludges that result from pulp and paper operations to produce an energy source such as ethanol. In another study, Duff et al. (1995) focused on the conversion of low value cellulosic substrates from fiber recycling and deinking operations to fermentable sugars.

CONCLUSION

A variety of enzymes from plants and microorganisms have been reported to play an important role in an array of waste treatment applications. Enzymes can act on specific recalcitrant pollutants to remove them by precipitation or transformation to other innocuous products. The main advantages of using enzymes in these processes are their favorites and unique properties, their biodegradability and their high chemo- region and stereo-selectivity, resulting in the low by-product formation, all of which enables their progressive implementation.

They improve the quality of waste, including the transformation of Cyanide wastes, dyes, heavy metals, aromatic pollutants, solid wastes, surfactants and organophosphate substances as well convert waste materials from the food processing industry and pulp and paper industry to value added products such as fuels, feeds and commodity chemicals. However, a more extensive effort is required to overcome several bottlenecks: high enzyme cost, low activity and/or stability under given conditions and low reaction yields.

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Chapter 3

RESOURCE MANAGEMENT: AN INDIAN EARTHWORM'S EYE VIEW FOR COMPOSTING ORGANIC WASTES

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ABSTRACT

Technology has undoubtedly provided copious advantages, but simultaneously has also generated large quantities of waste which is discarded in the name of garbage. Not only industrial waste but even domestic waste is today just disposed and not handled. Most cities do not even have landfills as they just fill up the land. The per capita generation of solid waste for urban areas is about 0.55 kg/person per day and about 0.4 - 0.45 kg/per person per day for people living in rural areas (these values may vary depending on different types of survey activities). Most of the waste generally is dumped and burnt. The "NIMBY" (Not In My Back Yard) process is often prevalent. In India an active "group" of people try their best to salvage what they can for recycling from the dump sites. As waste is not segregated, most of the material that is salvaged from the dump site has already lost its quality. Today the world is moving towards Zero Waste Management. There are cases where countries are starting to adopt Zero Waste Goals as policy measures. The best way to handle the 80% of organics generated at the household level is to compost it. Composting is a controlled oxidative process that involves a heterogeneous organic substrate in the solid state, evolved by passing through a thermophilic phase leading to the production of CO_2, water, minerals and stabilized organic matter called compost.

Keywords: Waste management, vermicomposting, NIMBY, zero waste management

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INTRODUCTION

Solid waste management has emerged as one of the biggest challenges today in urban as well as rural India. The municipal bodies have been unable to adjust to the rapid changes that have led to both increased quantities and changes in the composition of the waste. The current situation, which gives rise to the indiscriminate dumping and burning of wastes, has a serious impact on air, land and water quality and causes a dramatic increase in health hazards in the urban environment.

As a response, in many cities, non-governmental voluntary organisations (NGOs) have started developing neighbourhood waste collection services, as well as initiating composting and recycling activities. These moves are backed up by new municipal solid waste management and handling rules published in 2000, which, among other recommendations, require source segregation and waste recovery.

Several alternatives have been proposed for solid waste management. Some recommend incineration. However, recycling the materials saves three to five times the amount of energy as incinerating these same materials would generate. Waste incineration encourages a one-way flow of materials on a finite planet, thus making the task of conserving resources and reducing waste more difficult, not easier.

Today the world is moving towards Zero Waste Management. There are cases where countries are starting to adopt Zero Waste Goals as policy measures. San Francisco has already achieved 52% landfill diversion and is hoping to reach zero by 2020. Even after the directive from the Supreme Court of India (MSW Rules 2000) to be implemented before 31st December 2003, Sulurpet in Andhra Pradesh was one of the few municipalities who had implemented source segregation, door to door collection and composting, later tried by Namakkal and Kanyakumari in Tamilnadu. Most often it was the officer heading the division and his/her passionate role in the cause effected implementation.

The Zero Waste Management model should concentrate on the challenge to recover the recyclable fraction of household refuse, at least 95% of the total amount generated (80% organic wastes, 15% inorganic) - so that only 5% would need to be handled by the Municipal Corporation.

The best way to handle the 80% of organics generated at the household level is to compost it. Composting is a controlled oxidative process that involves a heterogeneous organic substrate in the solid state, evolved by passing through a thermophilic phase leading to the production of CO_2, water, minerals and stabilized organic matter called compost (Diaz et al., 2002). Several methods of composting are in vogue in India and any one or many methods of composting can be applied in given situations. Selecting a suitable method of composting appropriate to the place based on resource availability as well as limitations should be applied to evolve a most suitable model for that given place. Anaerobic composting in pits dug in ground used to be prevalent, but in large scale application such methods can cause ground water contamination. Biogas generation through regulated anaerobic digesters are also effective in not only handling waste but also in providing fuel for the household. It is up to the resident or the agency to decide the *modus operandi* based on the availability of land, manpower and resources. It is also desirable that in any municipality, more than one method is applied for effective handling of wastes. In this chapter we shall look into the possibilities of composting and waste water utilisation as the scope of this chapter limits to that but in no way belittles the other methods. Each and every method has its advantage as well as disadvantage.

COMPOSTING

Composting can be broadly classified into two types: the anaerobic and aerobic models. The anaerobic model had been the most prevalent once upon a time in all rural centres, when all litter and organic refuse was put into pits and closed. The manure is ready in six months, after which this manure was used as nutrient to the soils. Today with cropping patterns having changed and the need for quick availability of manure; it is indeed desirable to resort to the aerobic model of composting. Biodegradation of natural materials produces valuable compost as the major product, along with water and carbon dioxide. The CO_2 produced does not contribute to an increase in greenhouse gases because it is already part of the biological carbon cycle.

In rural sectors, especially in agriculture-predominant settlements, the NADEP composting came into practice. This involves construction of tanks specifically designed for NADEP with air vents on the sides of the tank. The most convenient prescribed size for a NADEP tank is 12 feet (L) X 5 feet (W) X 3 feet (H). To construct this one requires:

Bricks	1,200 numbers
Cement	3 bags
Sand	20 ft^3

Each tank can take in 1,350 to 1,400 kg of a dry and green waste combination. This needs to be supplemented with about 100 kg of cattle dung, about 1675 kg of fine sieved soil and about 1500 litres of water. The top of the tank is sealed with soil and a shed is preferably put on the tank. About 2.5 tons of compost is obtained from each tank in about 90 to 120 days. Though this is indeed a good practice, windrow method of composting has taken over the NADEP method to save costs, space and soil.

For municipal solid waste the windrow method is one very suitable method. Shredding of the waste is essential to increase surface area of the organic matter. This shredded waste should be placed into windrows of any convenient length but with width preferably not exceeding 4 to 5 feet and the height not exceeding 4 to 5 feet. Such systems can provide easy turn over. In certain situations bigger piles can also be set up; however this shall demand machinery like front-end loaders to turn over the piles and spraying water. For effective composting, care is taken to see there is air space within the pile, that the moisture content is at least 60% and the C: N ratio is less than 40. To make windrow composting more effective, it is better to adopt the biodung method of composting.

The biodung method gives an advantage of an aeration chamber at the base made with twigs, which enables quick heating of the pile or the windrow. The added advantage in this method which also suggests the covering of the windrow with a polythene sheet is the capability of moisture retention and a high build up of temperature inside the pile, which facilitates the destruction of unwanted seeds as well as any pests or parasites in the waste used. The windrow needs an occasional turnover at specific periods. The manure is ready in about 45 days to 60 days.

However those desirous of producing vermicompost can transfer the biodung material after 30 days and cooling to vermicompost.

One of the important methods of composting is VERMITECH (term coined by Ismail, S.A) – that is application of earthworms in any bioprocess.

Earthworm diversity poses challenges in culturing them or applying them in the process of vermicomposting. Solid organic waste management through earthworms has been applied in several ways depending on the type of earthworm species. The procedure for handling small quantities of waste generated from households (indoor composting) is a little different from that applied in handling larger quantities of biomass from markets and agriculture (outdoor composting). Vermicomposting could be defined as "the combination of biological processes, design and techniques to systematically and intensively culture large quantities of one or more species of earthworms to speed up stabilization of organic waste materials, which are eaten, ground and digested with the help of other micro organisms like bacteria, fungi and other smaller animals". Organic matter then naturally gets converted into much finer particles like castings (faecal pellets from the earthworms). This compost is active microbially and important plant nutrients are found here in a form available to plants.

VERMICOMPOSTING

1. Vermicomposting Using Local Varieties of Earthworms

Of the species of earthworms that have been identified in the world, five hundred and nine species of earthworms have so far been identified in India alone and it is indeed easy to collect the epigeics and anecics from garden soils after monsoon spells.

> "Identify worm-inhabited soils where presence of earthworm castings on the soil surface is visible. Mark an area 1m x 1m. Dissolve 500g jaggery (also called as native or brown sugar or unrefined sugar) and 500gm freshly dropped cattle dung in 20 litres of water. Sprinkle on the marked area. Cover with straw, leave cattle dung lumps and cover with an old jute (gunny) bag. Keep watering for about 20 to 30 days. Then move the gunny bag and you will notice a combination of native worms there. Collect them and use them."

These earthworms can be cultured or used in composting applying simple procedures either in pits, crates, tanks, concrete rings or any containers (Ismail, 1997, 2005).

Organic material to be used is recommended only after pre-processing or pre-digestion of respective material through partial anaerobic phase (done under black polythene cover or with a clay seal layer). The biodung composting technology is highly recommended by us as a pre-digestion mechanism. Local species of earthworms that we generally have used in vermitech (vermes= earthworms; tech= technology) in India are a combo of *Perionyx excavatus* and *Lampito mauritii*.

2. Vermicomposting Using Exotic Species of Earthworms

Exotic species of earthworms have also been used in India for vermicomposting. Internationally three species of earthworms have received acclaim for vermicomposting, they being *Eisenia fetida* and *Eudrilus eugeniae*, which are exotic, and *Perionyx excavatus*, which is endemic. *Lumbricus rubellus* has also been used in certain cases.

Succession of Microorganisms in the Process of Composting and the Quality of Microorganisms in Vermicompost

The process of composting, although shows the occurrence of different microorganisms such as bacteria, fungi, actinomycetes, phosphate solubilizers and the microorganisms involved in the Nitrogen cycle; succession is shown in the quantity of microbes depending upon the nature of the substrate, the age of the compost, the ambience created by the existing microbes to its successors and also the physical and chemical characteristics.

Among the major groups of microbes such as bacteria, actinomycetes, fungi, succession can also be explained with reference to the diversity within each group of microorganisms. In the entire microbial succession, decomposers are succeeded by the biofertilizers during the composting process. This research has been extensively carried out in our laboratories with credits to Dr. Priscilla Jebakumari, and Dr. Dhakshayani Ganesh.

The majority of the microorganisms in the initial stages of the composting are the heterotrophic bacteria, which rely on the oxidation of the large amount of organic Carbon. It reduces during the thermophilic phase till the formation of the biodung compost. This then increases in vermicompost due to the passage of the material through the earthworm and the presence of the assimilable C, in the gut and the cast of the earthworms (Lavelle et al., 1992).

The role of microorganisms in the Nitrogen cycle is very prominent. There is increased presence of ammonifiers in the initial stage of composting, which correlates with the high amount of protein degradation and the microbial contribution to reduce C:N. Nitrifiers however increase from the initial to the final stages. The products of the ammonifers create an environment for the multiplication of nitrifiers which utilize ammonia and convert it to nitrite and nitrate. To substantiate this extra-cellular ammonia nitrogen decreases steadily from the initial higher values during the entire composting process. The ammonification process is reported to increase due to high temperature (Prasad and Powar, 1997).

Nitrification potential as indicated by NO_2- N decreases with composting time. The NO_2 production drops and stabilizes to low levels during the later stages of composting till no further decomposition can take place, as the C: N ratio gets stabilized (Tiquia et al., 2002).

The NO_3 production increases till about the 14^{th} day of composting thereafter declining till the 35^{th} day. This drop could be due to high temperature, as nitrification is inhibited by high temperature and could also indicate microbial immobilization. The dominance of the extra-cellular production of NO_3 on the worm worked vermicompost could be the result of the enhanced nitrifier activity.

Amount of phosphate in compost samples throughout the process and vermicompost records a steady increase from the initial phase of composting till vermicompost. This is due to the increased phosphatase activity in vermicompost as earthworm casts and feces exhibit higher phosphatase activity (Mansdell et al., 1981 and Satchel and Martin, 1984). It is also observed that PO_4 production shows a decline at about the 21^{st} day of composting which correlates with the reports of Gupta (1999) that high NH_4^+ concentration retards P fixation. Phosphate solubilizers also steadily increase throughout the process. So in terms of succession ammonifiers which are the major organic N decomposers are succeeded by the nitrifiers and phosphate solubilizers.

Oxidation of sulfur and sulfate compounds is elaborated by aerobic obligate autotrophs. *Thiobacillus thiooxidans* and *Thiobacillus thioparus,* recorded in vermicompost attribute to the reason for vermicompost being capable of ameliorating sodic soils. The population density of the actinomycetes increases from the initial phase of composting till the maturation phase except for a period of decline in the thermophilic phase.

Actinomycetes occur after readily available substrate disappears in the early stages and colonize in the humification stage as the compost reaches maturity. It is also found that the optimum temperature of actinomycetes is $40\text{-}50^{o}$ C, which is also the temperature for lignin degradation in compost (Tuomela et al., 2000).

Fungal density decreases as the composting process progresses. Mucoraceous group of fungi commonly referred to as sugar fungi are observed in the initial and early phases of composting in agreement with the nutritional hypothesis. Species of *Aspergillus* dominate and are responsible for major degradation of initial organic carbon as they are known to elaborate cellullases and hemicellulases. A lignolytic fungi *Coprinus* sps is predominantly found to colonise the compost only towards the end when complex organic matter is biodegraded.

The thermophilic fungi records an increase in density and diversity during the thermophilic phase and these are known to bring about degradation of cellulose, lignin and pectin at a faster rate in conjunction with high temperature. The presence of *Trichoderma viridae* and *Trichoderma harzianum*, both potential biocontrol agents, during the composting process and to a larger magnitude in the vermicompost is noteworthy.

The density and diversity of algae increases progressively and maximum recorded in the vermicompost. Of special significance are the presences of algae such as *Oscillatoria* sp, *Anabaena* sp, and *Nostoc* sp which are known to enhance soil fertility.

To simplify the loading procedure for composting in Institutions and in the rural sectors where the availability of organic material is not in bulk, a four-tank system has been developed based on a combination of biodung and vermitech techniques that enables continuous compost production. In the same manner two-tank system is also suggested for lesser quantities of garbage.

FOUR TANK LOADING SCHEDULE

Harvesting of Compost

When the compost is ready for harvesting, moistening of the pit should be suspended for 3 to 4 days prior to harvesting. Spread the compost after harvesting, collect the worms, if any for further inoculation, air dry the compost and sieve through a 2.5-3 mm sieve. The material is then ready for use or to be packed for later use.

DAYS	TANK	PROCESS
000 – 030	01	Collection of biomass and cattle dung
030 – 060	01	Add cattle dung, water, cover with black polythene (Biodung)
	02	Collection of biomass
060 – 090	01	Inoculation of earthworms
	02	Biodung preparation
	03	Biomass collection
090 – 120	01	Vermicompost ready earthworms migrate from pit 1 to pit 2
	02	Vermicomposting
	03	Biodung preparation
	04	Biomass collection
120 – 140	01	Harvesting of compost and collection of biomass
	02	Vermicompost ready earthworms migrate from pit 2 to pit 3
	03	Vermicomposting
	04	Biodung preparation

BENEFITS

Composting is the best method of garbage handling given our temperature and situations. The type of composting applied shall depend on the given situation, crop and area. Biodung composting or windrow composting shall be the most preferred method for SWM. However due to the additional qualitative value of vermicompost, vermitech can be applied wherever necessary.

ECONOMICS

Whatever may be the technology applied, the selling price of manure in the market has a wide range depending on the type of outlet. The quality of manure is equally important and needs to be maintained. It is however desirable that the cost is kept low as it shall become affordable for purchase in tons by farmers.

Investment costs shall vary according to the space, land, and water and resource availability. To start a simple unit handling half ton of compostable waste per day through biodung windrow method shall require atleast 3000 ft^2. From one ton of waste generally 20 to 25% may result in manure.

EQUIPMENT

The need for mechanisation shall increase with more quantity of material that should be handled. For 1 to 2 tons of waste per day manual handling is sufficient. For large quantities, transport equipment, front-end loaders, pulverisers/shredders, windrow turners, screeners, packing equipment etc may be needed for composting the material. An area of about 5000 ft^2 shall suffice to handle one ton per day of garbage.

RECOMMENDED DOSAGE

Compost is essential for soils as organic matter plays a vital role in crop production. A general recommendation is given below; however suitable changes should be adopted as and when necessary depending on crop and the type of soil.

100 gm of compost is applied for a pot containing 8 to 10 kg soil.
1-10 kg of compost per tree, depending on age and size of tree.
4 to 5 tons of compost per hectare of land.
Regular watering and mulching of the land is important.
No chemicals should be sprayed over the compost pit.
Sprays of plant origin are recommended, only if necessary, for plants.

OTHER APPLICATIONS

Many industries produce two streams of waste water from their treatment units - the sewage treatment plant (STP) and the effluent treatment plant (ETP). Sludge from the STP can be handled very successfully with appropriate bulking materials and converted into vermicompost. Sludge from the ETP if free from heavy metals can also be handled with suitable bulking materials through modified biodung composting technologies.

P7 COMPOSTING

P7 is an abbreviation for seven pots. Yes those who wish to do composting at home and not desirous of using worms can buy seven flower pots. Observe whether the holes at the base of the pots are functional as water accumulation in pots can cause rotting of waste causing unpleasant smell. Name the pots as the seven days of the week. This means the vegetable waste of Monday shall be chopped and put in pot named Monday. Add a little cattle dung or sour curd (diluted in water) on top of the waste and sprinkle a little soil on it. Tuesday’s waste shall go in the Tuesday pot and so on. One reaches back to Monday only after 7 days and by this time the waste is under composting process. Keep continuing. Once in a way can give a turn to the contents with a stick. It takes more than 3 months for all 7 pots to be full. Leave for 15-20 days. All 7 pots are now ready with excellent potting mix. Sow the seeds of vegetables in each and have healthy organic vegetables at home. Buy 7 new pots and continue. Please avoid using cooked food waste till you are familiar with the composting process.

RING GARDEN

A more suitable compost-cum-nutrition garden especially for rural families as well as in urban if they have open space is the Ring garden. Excavate soil in the form of a circle of 3 feet diameter. The excavation should be in the form of a frying pan with the centre dept to about 1.5 feet tapering towards the circumference. The soil excavated is placed as a circular mound around the circumference of this ring. Start to add waste in the pit. It is desirable to inoculate with microorganisms by adding freshly laid cattle-dung or sour curd diluted in water. After about 15 to 20 days when compost is getting formed plant small plants like coriander, mint and greens on the inner part of the mound and vegetables such as okra, brinjal and tomato on the outer side of the mound. This shall be an effective method to handle wastes as well as to have a nutrition garden. If the soil is good, endemic earthworms shall by themselves reach the pit and contribute to the formation of vermicompost as well.

CONCLUSION

Composting is a process in which most of the nutrients are mineralized; the remaining complex substrates such as lignocelluloses could also help in the formation of humus. Moreover the microbial population in the compost continues its activities in the soil on application, acting as a “factory” enabling the organic process. The propagation of modern concepts where dried and powdered organic material is recommended for application to soils may initiate a thermophilic phase in the soils damaging tender roots. Care has to be taken that appropriate composting procedures are applied to prepare manure from organic wastes. Come let us start doing this *for Earth’s sake*.

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Chapter 4

MANAGEMENT OF AGRICULTURAL WASTES USING MICROBIAL AGENTS

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ABSTRACT

Agricultural wastes are among the causes of environmental pollution which also shorten the fallow period, which reduces the time for aerobic degradation of the crop residue. The common practice to overcome the accumulation of un-decomposed crop residue is open burning of straw and stubbles which has been also used traditionally to sanitize agricultural fields against pests and diseases. Due to environmental concerns, thermal straw management is now being reconsidered in many regions of the world and has been widely banned in China and India. Biological degradation, for both economic and ecological reasons, has become an increasingly popular alternative for the treatment of agricultural, industrial, organic as well as toxic waste. Agriculture wastes recycling can bring tremendous benefits to agriculture and land management in long run. In addition there are the benefits of a cleaner environment, a healthier habitat and an intelligent use of all available recyclable resources without condemning them as wastes.

Keywords: Agricultural waste, composting, environmental issue, microbial degradation

INTRODUCTION

Increasing global population has been reciprocated with increase in agricultural produce. Approximately 40% of the world's population (2.6 billion people) depend on agriculture for their livelihood (World Bank, 2008). In 2012, worldwide production of few important crops alone has reached approximately 62 billion metric tons which included staple food crops like

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rice, maize, wheat, sugar cane and many vegetables (FAOSTAT, 2012). The intensification of crop production resulted in increased yields but also in larger amounts of plant residues which include mainly leaves, straws, cereals, corncobs etc. In many countries, these materials are generally used as animal feeds. Biomass takes the form of residual stalks, straw, leaves, roots, husk, nut or seed shells, waste wood and animal husbandry waste. A huge amount of these materials are left on farmlands to be decomposed by microorganisms such as Bacteria and fungi (Jadav et al., 2013). Altogether approximately 140 billion metric tons of biomass is generated globally every year from agriculture (UNEP, 2007). Lignocellulosic materials alone, in the form of agricultural wastes, are accumulated at a rate of 3480 Trillion grams per year (Pathak and Chaudhary, 2013). About 900 million tons of rice straw is produced worldwide annually, more than 90% being produced in Asia (Adenipekun and Dada, 2013). In China, crop straw waste exceeds 100 million tons/year (Wang et al. 1998). In Japan, one of the main agricultural residues is rice straw, about 9.6 megaton of which is produced annually (Sasaki et al., 2010). In Saudi Arabia as well as other countries in the Near East region, agricultural residues (AGR) production is more than 440 million tons., Most of these residues are either burned in the field or utilized in an inefficient way (Sadik et al., 2010).

Agricultural wastes are among the causes of environmental pollution which also shorten the fallow period, which reduces the time for aerobic degradation of the crop residue. Cellulose in natural substrates is persistent in the environment and remains as an environmental pollutant (Haruta et al., 2002). The common practice to overcome the accumulation of undecomposed crop residue is open burning of straw and stubbles which has been also used traditionally to sanitize agricultural fields against pests and diseases (Devevre and Horwaath, 2000). Due to environmental concerns, thermal straw management is now being reconsidered in many regions of the world and has been widely banned in China and India (Bierke et al., 2008). The recognition that environmental pollution is a worldwide threat to public health has given rise to a new massive industry for environmental restoration. Yearly accumulation of these agricultural residues causes deterioration of the environment and huge loss of potentially valuable nutritional constituents which when processed could yield food, feed, fuel, chemicals and minerals. Agricultural residues when dumped in open environment constitute health hazard due to pollution and support for the growth of microorganisms (Saranraj et al., 2012). Biological degradation, for both economic and ecological reasons, has become an increasingly popular alternative for the treatment of agricultural, industrial, organic as well as toxic waste. Insufficient and improper disposal of agricultural wastes has led to acute environmental pollution. (Kadarmoidheen et al., 2012). The recycling of agricultural wastes can bring tremendous benefits to agriculture and land management in a long run.. In addition there are the benefits of a cleaner environment, a healthier habitat and an intelligent use of all available recyclable resources without condemning them as wastes (Sadik et al., 2010).

As raw materials, biomass wastes have attractive potentials for large-scale industries and community-level enterprises (UNEP, 2009). Their conversion into useful products may ameliorate the problems they cause. The bioconversions of agricultural wastes are mainly carried out by the microbial community which involves bacteria, fungi, actinomycetes etc. Many of these communities degrade a wide spectrum of agricultural compositions while some specific degradation activities are also observed. Hence the role of microorganisms and the mechanisms which they use for the degradation of agricultural waste biomass need to be discussed.

Composition of Agricultural Wastes

Wastes coming out of agricultural activities composed of a wide spectrum of organic and inorganic materials such as plant residues, animal excreta in the form of slurries and farmyard manures, compost, soiled water and silage effluent, plastic, scrap machinery, fencing, pesticides, waste oils and veterinary medicines etc. As the main proportion of wastes is plant materials, agricultural wastes contain a high proportion of cellulosic, hemicellulosic and lignin, collectively known as lignocellulosic matter (Sachez, 2009), along with smaller amounts of pectin, protein, extractives (soluble nonstructural materials such as nonstructural sugars, nitrogenous material, chlorophyll and waxes) and ash. In general cellulose and hemicelluloses constitutes 75 to 80% while lignin constitutes only 14% of common agricultural waste but in some cases up to 99% of cellulose, 85% hemicelluloses and 40% lignin have been found in agricultural residues (Table 1, Kumar et al., 2009).

Table 1. Cellulose, Hemicellulose, and Lignin Contents in Common Agricultural Residues and Wastes. (Courtesy: Kumar et al., 2009 and Boonmee, 2012)

Lignocellulosic material	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Bagasse	44	23	20
Peanut shell	22.1	12.1	35.2
Rice hull	49.1	9.6	12.9
Rice straw	33	26	7
Sugarcane leaf & stalk	40	29	13
Sorghum leaf & stalk	31	30	11
Hardwood stems	40-55	24-40	18-25
Softwood stems	45-50	25-35	25-35
Nut shells	25-30	25-30	30-40
Corn cobs	45	35	15
Grasses	25-40	35-50	10-30
Paper	85-99	0	0-15
Wheat straw	30	50	15
Sorted refuse	60	20	20
Leaves	15-20	80-85	0
Cotton seed hairs	80-95	5-20	0
Newspaper	40-55	25-40	18-30
Waste papers from chemical pulps	60-70	10-20	05-10
Primary wastewater solids	8-15		
Solid cattle manure	1.6-4.7	1.4-3.3	2.7-5.7
Coastal bermudagrass	25	35.7	6.4
Switch grass	45	31.4	12
Swine waste	6	28	na

Each year photosynthetic fixation of CO_2 yields more than 10^{11} tons of dry plant material worldwide and almost half of this material consists of cellulose. Cellulose is a homopolymer consisting of glucose units joined by β-1, 4 bonds. The disaccharide cellobiose is regarded as the repeating unit in cellulose in as much as each glucose unit is rotated by 180° relative to its neighbour. The size of cellulose molecules (degree of polymerization) varies from 7000 to 14,000 glucose moieties per molecule in secondary walls of plants but may be as low as 500 glucose units per molecule in primary walls (Ljungdahl and Eriksson, 1985). Cellulose almost never occurs alone in nature but is usually associated with other plant substances. This association may affect its natural degradation. Cellulose fibrils are embedded in a matrix of other polymers, primarily including hemicelluloses, pectin, and proteins (Leschine, 1995). Cellulose is earth's major biopolymer and is of tremendous economic importance around the globe. Cellulose is the major constituent of raw materials like cotton (over 94%) and wood (over 50%) and is the primary structural component of the plant cell wall. Cellulosic biomass is a complex mixture of carbohydrate polymers known as cellulose, hemicellulose, lignin and a small amount of compounds known as extractives. Examples of cellulosic biomass include agricultural and forestry residues, municipal solid waste, herbaceous and woody plants, and underused standing forests. Cellulose is composed of glucose molecules bonded together in long chains that form a crystalline structure (Kotchoni et al., 2003). Cellulose and hemicelluloses are fibrous, tough, water insoluble substance. The degradation of cellulosic biomass represents an important part of the biosphere's carbon cycle. (Haruta et al., 2002). Cellulose accounts for 50% of the dry weight of plant biomass and approximately 50% of the dry weight of secondary sources of biomass, such as agricultural, industrial, and domestic wastes (Coughlan and Mayer 1992). The bunch consists of 70% moisture and 30% solid; of which holocellulose accounts for 65.5%, lignin 21.2%, ash 3.5%, hot water-soluble substances 5.6% and alcohol-benzene soluble 4-1% (Kadarmoidheen et al., 2012).

Herbaceous materials and agricultural residues generally contain a higher proportion of hemicellulose (up to 33%). The name hemicelluloses which can generally be defined as non-cellulosic cell wall polysaccharide, was first introduced by Schulze in 1891 for the fractions extracted from plant materials with dilute alkali (Schulze, 1981). Hemicellulose (also named as Glycans) is a mixture of polymers made up from xylose, mannose, galactose, or arabinose (Schyns, 1997). Table 2 shows the approximate percentage of different class of hemicelluloses in various crop residues.

Table 2. Percentage of different class of hemicelluloses in various agro wastes (Courtsey: Schyns, 1997)

Hemicellulose	Cotton wood	Pine	Straw	Bagasse
Glucan	43.4	42.4	31.9	38.8
Xylan	13	5.9	19	21.4
Mannan	2	11	0.2	0.2
Arabinan	0.3	1.3	2.1	1.4
Galactan	0.3	2.3	0.6	0.3
Total	58.3	62.9	53.8	62.5

Percentage based on dry raw material.

Hemicellulose is much less stable than cellulose (Bernfeld, 1955; Saranraj et al., 2012). The main feature that differentiates hemicellulose from cellulose is that hemicellulose has branches with short lateral chains consisting of different sugars. These monosaccharides include pentoses (xylose, rhamnose, and arabinose), hexoses (glucose, mannose, and galactose), and uronic acids (e.g., 4-*o*methylglucuronic, D-glucuronic, and D-galactouronic acids). The backbone of hemicellulose is either a homopolymer or a heteropolymer with short branches linked by β (1,4) glycosidic bonds and occasionally β (1,3) glycosidic bonds. Also, hemicelluloses can have some degree of acetylation, for example, in heteroxylan. In contrast to cellulose, the polymers present in hemicelluloses are easily hydrolyzable. These polymers do not aggregate, even when they cocrystallize with cellulose chain (Kumar et al., 2009; Soliman et al., 2013). A study by Harada et al. (2005) showed the composition of hemicelluloses in rice bran. Rice bran hemicellulose used in that work contains almost equal amounts of arabinose and xylose as main components, and small amounts of glucose and galactose: xylose, 45.8%; arabinose, 42.5%; galactose, 4.7%; glucose, 4.1%; galacturonic acid, 1.5%; rhamnose, 1.1%; ribose, 0.3%; fructose, glucuronic acid, and mannose, undetectable (Harada et al., 2005).

Another important component of plant cell is pectin which constitutes an integral part of agro waste mainly fruit waste (Madhav and Pushpalatha, 2002). The biological function of pectin is to cross-link cellulose and hemicellulose fibers, providing rigidity to the cell wall (Abbott, 2008). Pectins are composed of a main backbone of α-1, 4-linked D-galacturonic acid, and consist of two regions: the "smooth" region and the "hairy" region. The "smooth" region contains residues of D-galacturonic acids that can be methylated or acetylated, while in the "hairy" region, the backbone of D-galacturonic acids residues is interrupted by α-1,2-linked Lrhamnose residues. Moreover, in the hairy region, long side chains of L-arabinose and Dgalactose residues can be attached to the rhamnose residues (Dongowski, 2000; DeSouza, 2013; Prade et al., 1999).

Lignin ranks second only to cellulose as the most abundant naturally occurring polymer in the biosphere (Nickelsen, 1993). Lignin is a complex, large molecular structure containing cross-linked polymers of phenolic monomers. It is present in the primary cell wall, imparting structural support, impermeability and resistance against microbial attack. Three phenyl propionic alcohols exist as monomers of lignin: coniferyl alcohol (guaiacyl propanol), coumaryl alcohol (*p*-hydroxyphenyl propanol), and sinapyl alcohol (syringyl alcohol). Alkyl-aryl, alkyl-alkyl, and aryl-aryl ether bonds link these phenolic monomers together (Perez et al., 2002). Lignin is one of the more refractory macromolecules to be found in all vascular plants which represents one-third of dry mass of plant material. It is a three dimensional, highly inter-linked polymer of large molecular weight, build up from substituted phenylpropene units (Reale et al., 2004). Since it is specific for vascular plants, it serves as an indicator for the fate of plant-derived organic matter in soils (Hedges and Mann, 1979; Guggenberger et al., 1994). Due to its aromatic nature and the various types of bondings, lignin exhibits a stronger resistance to degradation at initial stages of microbial decomposition than other plant constituents (Bierke et al., 2008). Lignocellulosic biomass, which consists mainly of cellulose (35–50%), hemicellulose (25-30%) and lignin (25–30%) (Wongwilaiwarin et al., 2010) is a potential source of energy, fuels, chemicals (Wang et al., 2011) and it is the most abundant renewable resource on earth. For example, high yielding maize and rice can produce field residues as much as 11 t/ha and 25 t/ha annually in most developing countries. (El-Tayeb et al., 2012).

The composition of agricultural waste in an agriculture province thus depends upon the type of crop plant. For an example rice plant which is the staple food in many countries, supplies 1,700 to 3,470 kg ha^{-1} of organic matter annually to paddy fields of which more than 65% of them were derived from plant residues (Rui et al., 2009). Rice plant residues includes mainly roots and straw of which straw is composed of cellulose (32%–37%), hemicelluloses (29%–37%), and lignin (5%–15%) (Sasaki et al., 2010). In a study conducted by Kadarmoidheen et al. (2012) for the biodegradation of cellulosic waste materials viz., paddy straw, sugarcane bagasse and banana stalks, the highest cellulose content of 36.23% was recorded with banana stalks followed by sugarcane bagasse and paddy straw which contained 35.64%, 34.82% respectively. The highest hemicellulose content of 24.82% was recorded with sugarcane baggase followed by banana stalks and paddy straw which contained 21.36% and 21.24% hemicelluloses respectively.

ROLE OF MICROORGANISMS IN THE DEGRADATION OF AGRO-WASTE MATERIALS

Microorganisms are well known agents for their metabolic versatility for the degradation of biological wastes though the actual number of degraders of a target compound in a mixed culture may only represent 5-10% (Sarkar et al., 2011). As discussed above, the major portion of agricultural waste is biological in nature. Both fungal and bacterial or mixed consortia have been utilised and their efficiency has been well documented in the decomposition of biological wastes. These microbes belong to a diverse ecosystem i.e., from mesophilic and thermophilic zone to halophilic marine ecosystem (Kalisev et al., 2013).

Fungi Are the Most Active Decomposers

Fungi are structurally unique organisms, abound in various ecosystems and can colonise wide agricultural residues. Fungi possess extraordinary catalytic capability which can grow on solid substrates and secret diverse extracellular enzymes that breakdown various polymers to molecules by hydrolysis and oxidation that are then reabsorbed by fungal colony. Fungi are specifically suited for the task of biodegradation because (i) Many species are considered as safe for either direct consumption or the production of food components, (ii) they grow as hyphae hence able to grow on solid substrates and transport scarce nutrients such as nitrogen and iron, to a distance into the nutrient-poor lignocellulosic substrate that constitutes its carbon source (Hammel, 1997). (iii) they secret enzymes that degrade polymeric materials to products used subsequently as nutrients, (iv) they can grow at relatively low moisture content, (v) they synthesize many commercially useful products from agricultural and other wastes (Cohen and Hadar, 2001).

In recent years, decomposition of agricultural wastes such as coir pith, banana sheath (dried), sugarcane trash, millets waste, pulse waste, cotton stubble, rice straw, maize cob, sawdust of *Terminalia superba*, sugarcane bagasse, oat straw etc. with some white rot fungi (Pleurotus sp., *Daedalea elegans*, *Polyporus giganteus*, *Lenzites betulina*, *Coriolus sp.*, and *Cerrena maxima*) is gaining importance (Adejoye and Fasidi, 2009; Stepanova et al., 2003).

Theradimani and Sankaralingam (2012) reported the decomposition of some of these wastes with *P. eous*, *P. platypus*, *P. djamor* or *P. sajorcaju* by layer system. One layer of agricultural waste at 100 kg is spread uniformly in an area of 4 x 3 m2 under shade. Culture of *P. djamor* at 200 gms is applied over the substrate. Another 100 kg of substrate is spread over the first layer and urea is applied at rate of one kg to the substrate. This sandwiching is repeated to make a heap of 1,000 kg substrate with such 20 layers. A total of one kg of the fungus and five kg urea is required to decompose 1,000 kg waste. Water is sprinkled twice a day to maintain 50 -60 per cent moisture level. The heap is allowed to decompose for a month after which a turning is done. The waste undergoes degradation within 45 days. It has a narrow carbon: nitrogen ratio of 20:1 which can be used as organic manure (Theradimani and Sankaralingam, 2012). Different species of the white rot fungus *Pleurotus* was found to be effective in the degradation of various types of agrowaste. Adenipekun and Dada (2013) studied the degradation of cotton waste, rice straw and cocoa pod husk using *Pleurotus pulmonarius* and there was a consistent decrease in the dry matter of the treated substrate compared with the untreated one between 0-60 days. This was in line with Jonathan et al. (2010) who reported that dry matter reduced significantly from 88.74% in control to 86.80% in *Lentinus subnudus* and 86.55% in *Pleurotus tuberregium*. Another edible species of this genus, *Pleurotus citrinopileatus* degraded lignin, cellulose, hemicellulose and carbon content of both chemically as well as hot water treated agro waste sugarcane bagasse and produced in turn the edible and nutritious fruiting body (Pandey et al., 2012). In another study coffee pulp waste was degraded rapidly by two other species such as *Pleurotus flabellatus* and *Pleurotus eous*. These two and some other fungi like *Ganoderma lucidum*, *Chaetomium globosum*, *Aspergillus terreus*, *Phaerochaete chrysosporium*, *Fomes badius* caused a loss of organic matter in coffee agro wastes with a range of 22.6% to 24.7% up to 20^{th} day of treatment (Parani and Eyini, 2012). Production of extracellular plant cell wall degrading enzymes (cellulase, pectin lyase and polygalacturonase) by 58 fungal isolates representing 29 species and one variety related to 12 genera (*Alternaria*, *Aspergillus*, *Penicillium* and *Mucor*) was tested in an experiment by Al-Mahdi et al. (2012). *A. fumigatus* followed by *A. terreus* var. *aureus*, then *P. griseofulvum* were found to be the active cellulase producers. Whereas *P. glabrum* was active producer of pectinlyase (PL), while *Acremonium strictum* and *P. chrysogenum* appeared to be good polygalacturonase (PG) producers (Al-Mahdi et al., 2012). Mayer and Hillebrandt (1997) reported the autochthonic microbial degradation (bacteria and fungi) of potato pulp. This is one of the agricultural waste products obtained in high quantities during starch production which contains starch, cellulose, hemicelluloses, pectin, proteins, free amino acids and salts. Biodegradation activity was also observed in marine fungi such as *Aspergillus niger* and *Trichoderma viride*. *Trichoderma sp*. exhibited a tri-phasic lignocellulytic activity, i.e., lignolytic (on lignin), hemicellulolytic (xylan) and cellulolytic (CMC) activities (Prasad and Sethi, 2014).

From the above discussion we came to know about the constituents of agricultural wastes and the potential role of microbes for their degradation. So the microbial degradation of some important components of lignocellulosic agro wastes such as cellulose, hemi-cellulose, lignin, pectin etc. are elaborately discussed henceforth.

Degradation of Cellulosic Agro Wastes by Fungi

Agricultural wastes contain a high proportion of cellulosic matter which is easily decomposed by a combination of physical, chemical and biological processes but the association of cellulose with other plant substances affects its biodegradation (Kadarmoidheen et al., 2012). Cellulose is naturally degraded by the enzyme cellulase, synthesized by microorganisms mainly fungi, during their growth on cellulosic materials. Though fungi in general are well known agents of decomposition of organic matter, in particular they are the main cellulase producing microorganisms (Carlile and Watkinson, 1997). A few bacteria and actinomycetes have also been reported to yield cellulase activity. A number of species of the most primitive group of fungi, the anaerobic Chytridomycetes, are well known for their ability to degrade cellulose in gastrointestinal tracts of ruminant animals. By 1976, over 14,000 fungal species capable of degrading cellulose had been isolated, but only a few of them were subjected to in-depth studies (Dashtban et al., 2009). Fungal cellulose utilization is distributed within the entire kingdom, from the protist-like Chytridomycetes to the advanced Basidiomycetes (DeSouza, 2013). Within the approximately 700 species of Zygomycetes, only certain members of the genus *Mucor* have been shown to possess significant cellulolytic activity. Members of genera that have received considerable study with respect to their cellulolytic enzymes and/or wood-degrading capability include *Bulgaria*, *Chaetomium*, and *Helotium* (Ascomycetes); *Coriolus*, *Phanerochaete*, *Poria*, *Schizophyllum* and *Serpula* (Basidiomycetes); and *Aspergillus*, *Cladosporium*, *Fusarium*, *Geotrichum*, *Myrothecium*, *Paecilomyces*, *Penicillium*, and *Trichoderma* (Deuteromycetes) (Lynd et al., 2002). Among fungi well characterised cellulase system has been observed in white rot fungus *Phanerochaete chrysosporium*, Soft-rot fungi *Fusarium solani*, *Penicillum funiculosum*, *Talaromyces emersonii*, *Trichoderma koningii* and *Trichoderma reesei*. Crude enzymes produced by *Trichoderma* and *Aspergillus* are commercially available for agricultural use (Saranraj et al., 2012; DeSouza, 2013). Species of *Aspergillus* (*A. flavus*) have decomposed different form of cellulose like carboxymethyl cellulose with endoglucanase activity (Anita et al., 2013). The cellulase systems of the mesophilic fungi *Trichoderma reesei* and *Phanerochaete chrysosporium* are the most thoroughly studied. Several thermophilic fungi can degrade cellulose faster than *T. reesei*. Among aerobic cellulolytic bacteria, species from the genera *Cellulomonas*, *Pseudomonas*, and *Streptomyces* are the best studied (Beguin and Aubert, 1994).

Both aerobic and anaerobic fungi are efficient cellulose degraders of various agro- waste materials.

Aerobic Degradation

The ability to degrade cellulose aerobically is widespread among fungi and is especially well represented among the Ascomycota and Basidiomycota (groups now to consider encompassing the corresponding asexually reproductive states formerly grouped separately as Deuteromycota) (Deboer et al., 2005). One way in which fungi breaks down cellulose chain is by generating radicals that can react with the cellulose via a free radical mechanism. Fungi produces hydrogen peroxide (H_2O_2) in an aerobic environment, hydrogen peroxide dissociates into hyroxyl radicals. The hydroxyl radicals react with the cellulose chain and break it down. Some fungi also have enzymes that catalyze the oxidation reaction of a large cellulose chain or the lower molecular weight oligomers produce by enzymatic hydrolysis. For example, if peroxide radicals are present in an environment then they can break the C2-C3 bond in cellulose bond to provide aldehyde cellulose (Figure 1). The aldehyde cellulose is very reactive and reacts with water to break into small fragments (Lenz, 1993).

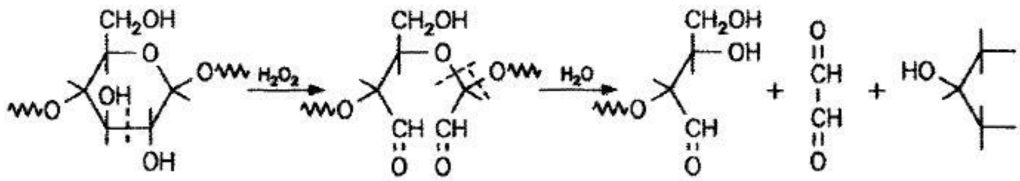


Figure 1. Production of Hydrogen peroxide by fungi in aerobic environment and the gradual degradation of cellulose by breaking of C2-C3 bond by peroxidases (Courtesy: Lenz, 1993).

Anaerobic Degradation

Fungi play a very minor role in the degradation of cellulose under anaerobic condition. Some fungal species, belonging to the phylum Chytridiomycota, that inhabit the gastrointestinal tracts of ruminants, show fermentative degradation of cellulose (Deboer et al., 2005). Anaerobic fungi and anaerobic degradation of cellulose usually constitute a central process in the digestion of feed by ruminants. Anaerobic fungi, bacteria and perhaps ciliate protozoa, actively degrade fiber in the rumen. Some anaerobic ruminant fungal strains *Neocallimastix sp*. (strain LM-1), *Piromonas sp*. (strain SM-1) and *Sphaeromonas sp*. (strain NM-1) could decompose wheat straw cellulose. All three anaerobic fungi grew in the straw-containing medium in which a loss of dry weight from the cultures indicated degradation of straw to various degrees. β-Glucosidase, carboxymethyl cellulase (CM-cellulase), azure cellulase, β-xylosidase, and xylanase enzyme activities were detected in the supernatants from the medium containing straw after growth of the three fungi (Gordon and Phillips, 1989). It has been observed that the presence of some hydrogen-Consuming methanogens like *Methanobacterium arboriphilus*, *Methanobacterium bryantii*, or *Methanobrevibacter smithii* increased the level of cellulose fermentation by 5 to 10% in cultures of several genera of anaerobic fungi. When *Neocallimastix* sp. strain L2 was grown in coculture with methanogens, the rate of cellulose fermentation also increased relative to that for pure cultures of the fungus. In that interaction with methanogens, the fermentation products shifted more to acetate and less lactate, succinate, and ethanol (Marvin-sikkema, 1990). Similarly, cellulolytic activity of anaerobic rumen fungi *Sphaeromonas communis* increased when co-cultured with two ruminant bacteria *Selenomonas ruminantium* and *Methanobrevibacter ruminantium* (Bernalier etal., 1991).

Mechanism of Cellulose Degradation by Fungi

The adsorption of cellulolytic enzymes to the surface of cellulosic materials is a prerequisite for degradation and this process depends upon the physical characteristics of cellulose. Cellulose crystallinity is considered one of the most important structural parameters affecting hydrolysis yield. According to some researcher a reverse relationship exists between crystallinity and percentage of enzymatic hydrolysis by cellulolytic fungi. On the contrary, some investigators have shown that crystallinity is not directly related to the intensity of subsequent enzymatic breakdown (Chosson, 1988). Cellulase hydrolyses the β-1, 4-glycosidic linkage of cellulose. The complete enzymatic hydrolysis of cellulosic materials needs different types of cellulase; namely endoglucanase, (1, 4-D-glucan-4-glucanohydrolase; EC 3.2.1.4), exocellobiohydrolase (1, 4-Dglucan glucohydrolase) and glucosidase (D-glucoside glucohydrolase). Figure 2 shows the schematic representation of enzymatic degradation of cellulose to glucose.

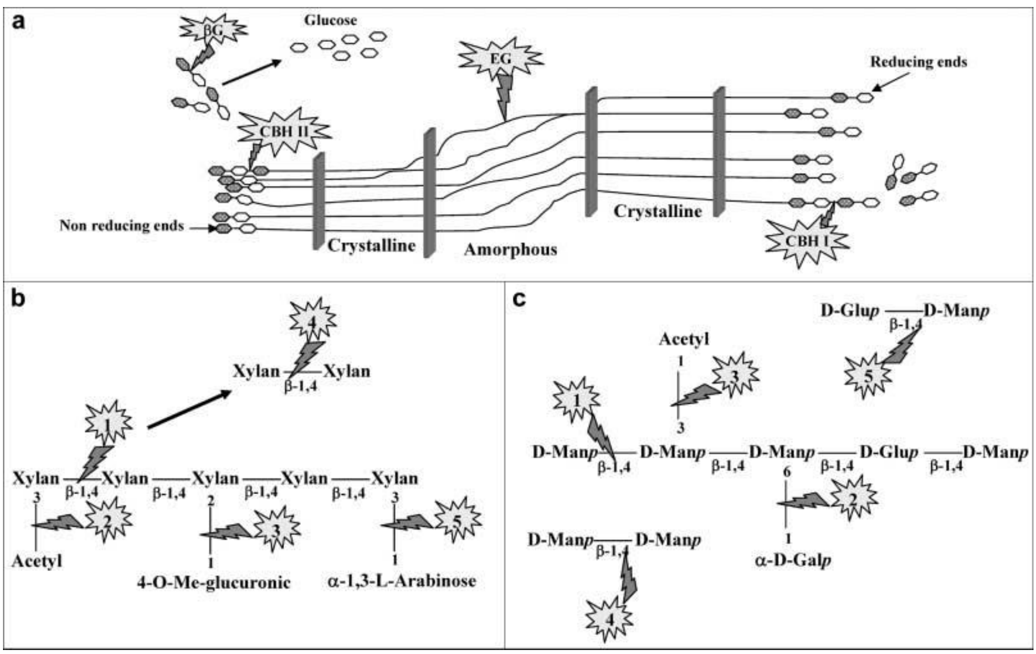


Figure 2. A. Enzymatic degradation of cellulose to glucose (CBHI Cellobiohydrolase I, CBHII cellobiohydrolase II, EG endoglucanases, β-G b-Glucosidase).

B. Enzymatic degradation of glucuronoxylans. 1 Endoxylanase, 2 acetylxylan-esterase, 3 α-glucuronidase. 4 β-xylosidase, 5 α-arabinose

C. Enzymatic hydrolysis of glucomannan. 1 Endomannase, 2 α-galactosidase, 3 acetylglucomannan-esterase, 4 β-mannosidase, 5 β-glucosidase (Courtesy: Perez et al., 2002).

Aerobic cellulolytic fungi and bacteria produce freely diffusible extracellular cellulose enzyme systems consisting of endoglucanases, exoglucanases and β-glucosidases that act synergistically in the conversion of cellulose to glucose (Mansfield and Meder, 2003). The cellulase system in fungi is considered to comprise three hydrolytic enzymes: (i) the endo-(1,4)-β-D-glucanase (synonyms: endoglucanase, endocellulase, carboxymethyl cellulase [EC 3.2.1.4]), which cleaves β-linkages at random, commonly in the amorphous parts of cellulose; (ii) the exo-(1,4)-β-Dglucanase (synonyms: cellobiohydrolase, exocellulase, microcrystalline cellulase, Avicelase), which releases cellobiose from either the nonreducing or the reducing end, generally from the crystalline parts of cellulose; and (iii) the β-glucosidase (synonym:

cellobiase [EC 3.2.1.21]), which releases glucose from cellobiose and short-chain cellooligosaccharides. Although β-glucosidase has no direct action on cellulose, it is regarded as a component of cellulase system because it stimulates cellulose hydrolysis (Leschine, 1995; Maheswari et al., 2000; DeSouza, 2013). A remarkable feature of the cellulase system is synergism; i.e., the action of a mixture of two or more cellulases is greater than the sum of the action of each component. Eriksen and Goksoyr (1976) purified one form each of endoglucanase, exoglucanase, and β-glucosidase from *Chaetomium thermophile* var. *dissitum*. Each of the cellulase components, when used singly, showed little activity on cotton, but when all the components were combined, extensive degradation of cotton occurred (Maheswari et al., 2000).

Bacteria Are Also Important Decomposers of Agro Waste Materials

Degradation of Cellulosic Biomass by Bacteria

Higher cellulolytic activity was also found in aerobic bacteria *Cellulomonas* sp., *Cellvibrio* sp., *Microbispora bispora* and *Thermomonospora* sp. as well as in anaerobic bacteria such as *Acetivibrio cellulolyticus*, *Bacteroides cellulosolvens*, *Bacteriodes succinogenes*, *Clostridium thermocellum*, *Ruminococcus albus* and *Ruminococcus flavefaciens*. Anaerobic bacteria possess a unique extracellular multienzyme complex, called cellulosome (Saranraj et al., 2012).

Another marine bacterium *Bacillus pumilus* exhibited degradation of 18 agro waste of Maize, Saw dust, Rice straw, Paper, Ragi straw, Maize leaves, Sugar cane Eucalyptus, Teak big leaves, Castor oil leaf, Nerium, Champak, Ficus, Crotoliria, Hongge, Mango leaves within the 5 weeks (Prasad et al., 2014). Soil bacterial strains of *Moraxella sp*., *Cellulomonas sp*. and *Planococcus sp*. have been used by Barman et al. (2011) to decompose agro waste containing plant stems, crop shells, wood shavings, saw dust etc.

Aerobic Bacterial Degradation of Cellulose

Aerobic cellulose degradation is known for several soil bacterial species in both filamentous (e.g., *Streptomyces*, *Micromonospora*) and non-filamentous (e.g., *Bacillus*, *Cellulomonas*, *Cytophaga*) genera (Lynd et al., 2002). Chosson (1988) observed the aerobic degradation of cellulose by *Cellulomonas uda* and found that amorphous celluloses are faster and more completely hydrolyzed than crystalline celluloses which was due a lower accessibility of crystalline celluloses and also at a low exo- endoglucanase ratio in the cellulase system excreted by *Cellulomonas.*

Anaerobic Bacterial Degradation of Cellulose

Most cellulose is degraded aerobically where as about 5–10% of cellulose is degraded in nature under anaerobic conditions. Fermentative degradation of cellulose is widely distributed among obligately anaerobic bacteria (e.g., *Acetivibrio*, *Clostridium*, *Ruminococcus*). The cellulose system of anaerobic microorganisms is clearly different from that of aerobic fungi and bacteria. The development of microbial communities that effect the degradation of cellulose and other abundantly produced plant cell wall polymers in anaerobic environments is one of the hallmarks of evolution. The ecology of cellulose degradation in anaerobic environments is very complex; it involves numerous, varied interactions of metabolically diverse microorganisms whose activities are influenced by a wide range of environmental factors. Anaerobic environments rich in decaying plant material are prevalent and tremendously varied. Not surprisingly, a wide range of equally varied cellulose degrading microbial communities has evolved. Bacterial and fungal degradation of cellulose and other insoluble polymers occurs exocellularly, either in association with the outer cell envelope layer or extracellularly. (Leschine, 1995).

The cellulases of most anaerobic microorganisms are organized into large, multiprotein complexes. None of the individual proteins in the complexes has been found to have significant activity against crystalline cellulose. Multiprotein cellulase complexes are produced by many diverse anaerobes, including *Bacteroides cellulosolvens*, *Clostridium cellulolyticum*, *Clostridium cellulovorans*, *Clostridiurn papyrosolvens C7*, *Fibrobacter* (formerly *Bacteroides) succinogenes*, *Ruminococcus albus*, *Rurninococcusflavefaciens* and the rumen fungus *Neocallimastixfrontalis*. Several of these cellulolytic anaerobes *(B. cellulosolvens, C. cellulovorans, R. albus), as* well as *Acetivibrio cellulolyticus* and *Clostridium cellobioparum,* have cell-surface localized cellulosome-like structures. (Leschine, 1995). In this system, enzymes are organized into large functional entities termed cellulosomes. The organization of enzymes into cellulosome concentrates and positions them in such a manner that promotes synergism among catalytic units. The advantages of these arrangements of cellulolytic enzymes are that, since the cellulosome is attached to the cell surface, the enzymes are located at the interface between the cell and the insoluble substrate. The products of cellulolysis (such as cellobiose) can pass inside the bacterium via extended fibrous materials that are present between the cell and cellulose (Perez et al., 2002).

In the absence of oxygen and certain other exogenous inorganic electron acceptors (e.g., nitrate, Mn(IV)F, e(llI), sulphate), cellulose is decomposed by the anaerobic community into CH_4, CO_2 and H_2O through a complex microbial food chain. Each stage requires the activity of its own kind of specific microorganisms. Cellulolytic microbes produce enzymes that hydrolise or depolymerize cellulose, thereby producing cellobiose, cellodextrins, and soluble sugars such as glucose, xylose, arabinose, mannose etc. (Barakat et al., 2014). By keeping cellobiose concentrations low and thus preventing inhibition of the cellulase system by this product of cellulose hydrolysis, noncellulolytic cellobiose fermenters may play a very important role in this process. The soluble sugars are converted to volatile fatty acids (VFA) by the process of acedogenesis which are further fermented by cellulolytic and other saccharolytic microorganisms to acetate, CO_2 and H_2 by the process of acetogenesis. Very little H_2 escapes into the atmosphere because it is immediately consumed by methanogens or homoacetogens and archaea which covert acetate, CO_2 and H_2 anaerobically to methane by the process of methanogenesis. Through the combined activities of several major physiological groups of microbes, cellulose is completely dissimilated to CO_2 and CH_4. Thus, as a source of CO_2 and CH_4, the anaerobic decomposition of cellulose plays a major role in carbon cycling on the planet. (Leschine, 1995; Perez et al., 2002).

Microbial Degradation of Lignin

Lignin degradation is in a central position in the earth's carbon cycle, because most renewable carbon is either in lignin or in compounds protected by lignin from enzymatic degradation such as cellulose and hemicelluloses (Hatakka, 2001). This environmentally recalcitrant organic material has been degraded by different microorganisms like Bacteria, Fungi and Actinomycetes. They are capable of producing various degrading enzymes, however, the degradation process is controversial against different lignin due to its complex structure and bonding to carbohydrate complexes. The differential reactivity of microbes with this substrate indicates that they may utilize different chemical strategies for its breakdown. Generally the phenyl propanoid polymers in the lignin prevent access to the cellulose and hemicellulose polymer for the efficient release of sugars, and subsequent fermentation to bioethanol, and hence the lignin must be removed first (Thakur, 2012; Arumugam et al., 2014).

Fungal Decomposition of Lignin

Macro & Micro Fungi are the more predominant organisms effectively involved in degradation of lignin. The Macro fungi are classified into two types according to their decay pattern: brown rot & white rot. The most effective lignin degraders in nature are white rot fungi which have the ability to degrade complex recalcitrant organic molecules into simple aromatic residues or its constitute compounds under aerobic environment. Micro Fungus degrades the lignin under aerobic & facultative anaerobic environment in soil as a result formation of quality manure and humus (Arumugam et al., 2014). Biological pretreatment comprises the use of microorganisms especially brown rot, soft rot and/or white-rot fungi to selectively degrade lignin and hemicellulose. Of these, white-rot fungi seem to be the most effective as they are potential producers of laccase (E.C.1.10.3.2), manganese peroxidase (MnP; E.C.1.11.1.13) and lignin peroxidise (LiP; E.C.1.11.1.14) enzymes that modify lignin (Thakur et al., 2013). A much smaller group of filamentous fungi has evolved with the ability to break down lignin, the most recalcitrant component of plant cell walls. White-rot fungi (e.g., *Phanerochaete chrysosporium*) are the microorganisms that most efficiently degrade lignin which possess the unique ability of efficiently degrading lignin to CO_2 with a process of non-specific oxidation, referred to as enzymatic combustion. *Phanerochaete chrysosporium*, *Pycnoporus cinnabarinus* and fungal isolates RCK-1 and RCK-3 were tested for their lignin degradation abilities when grown on wheat straw (WS) and *Prosopis juliflora* (PJ) under solid-state cultivation conditions. Fungal isolate RCK-1 degraded more lignin in WS (12.26% and 22.64%) and PJ (19.30% and 21.97%) after 10 and 20 days, respectively, than other fungi tested. *Phanerochaete chrysosporium* caused higher substrate mass loss and degraded more of holocellulosic content (WS: 55.67%; PJ: 48.89%) than lignin (WS: 18.89%; PJ: 20.20%) after 20 days (Kuhar et al., 2008). In another study by Thakur et al. (2013) the lignin removal was higher in WS (40%) compared to BS (29%) after 32 days of fermentation using white rot basidiomycete fungus *Pleurotus ostreatus*. Lignin removal over the entire fermentation period obtained in that study was found to be in the range of previously reported values of lignin degradation (up to 46%) of plant residue by much studied *Phanerochaete flavido-alba* (Lopez et al. 2006). In that study Maximum laccase activity of 14,189 and 8,118.5 U/g, and 562.80 and 344.57 U/g of manganese peroxidase were obtained on 8th day of fermentation with WS and BS respectively. White rot fungi *Coriolus zonatus* and filamentous fungi *Mycelia sterilia* and *Trichoderma reesei* were able to degrade lignin in oat straw up to 55% (Stepanova et al., 2003). Many tropical white rot fungal species

Daedalea elegans, *Polyporus giganteus* and *Lenzites betulina* showed their lignin degrading abilities on different Nigerian agricultural residues. Maximum mycelial extension of 4.5 cm was observed in *D. elegans* on sugarcane bagasse followed in order by sawdust of *T. superba*, maizecob and rice straw. Highest lignin reduction of 92.9% was recorded in maize cob followed by rice straw (84.1%) fermented with *Daedalea elegans* after 90 days (Adejoye and Fasidi, 2009). Zadrazil (1985) and Braun *et al.* (2000) reported loss in organic matter and lignin content of substrates brought about by the growth of white-rot fungi including *Pleurotus sajor-caju*, *Ganoderma lucidium* and *Lenzites betulina.* The lignin content of treated cotton waste degraded by the fungus reduced from 1.90% in the control to 1.45% with increasing incubation period. For cocoa pod husk it also reduced from 28.76% to 22.33% but in rice straw there was an increase from 13.59% to 22.33%. A significant increase in nitrogen percentage was observed in cotton waste and rice straw and a decrease was observed in cocoa husk incubated with *Pleurotus pulmonarius* (Adenipekun and Dada, 2013). Isikhuemhen and Nerud (1999) observed that white rot fungi produced extracellular lignin modifying enzymes, the best characterized of which were laccase, lignin peroxidase and manganese peroxidases. Many wood rotting fungi including *Aspergillus* and the thermophilic fungi *Myceliophora thermophila* and *Chaemotium thermophilium* produces laccases, an important lignin degrading enzyme. (Sanchez, 2009; Perez et al., 2002).

Some soft-rot fungi can degrade lignin, because they erode the secondary cell wall and decrease the content of acid-insoluble material (Klason lignin) in angiosperm wood. Soft rot fungi typically attack higher moisture and lower lignin content materials (Shary et al., 2007). The importance of biological delignification has been amply demonstrated frequently in various fields of biotechnology. Ligninolytic strains not only prevent pollution but have also been used for the bioconversion of industrial wastes into useful energy yielding chemicals (Hammel, 1989). With the removal of lignin barrier, cellulose becomes easily accessible for bioconversion. Delignification of forage crop residues enhances their digestibility and also improves their nutritive value (Reid, 1989; Parani and Eyini, 2012).

DECOMPOSITION BY BACTERIA AND ACTINOMYCETES

Bacteria can decompose lignin and probably can also further degrade the low-molecular-weight degradation components produced from lignin by fungi. Many strains are able to metabolize lignin-related compounds and some of them also mineralize and solubilize polymeric lignin. Cleavage of the different types of linkages in lignin, oxidations, demethylations and aromatic ring cleavages are catalyzed by bacterial enzymes. Lignin-degrading bacteria or their enzymes could find novel applications in biotechnology for the modification of the lignin biopolymer (Zimmermann, 1990). Bacterial lignin degrading enzymes provide advantages over fungal enzymes in terms of their production and relative ease of protein engineering. Lignin degrading bacteria have wider tolerance of temperature, pH and oxygen limitation than fungi (Elsalam and Hanafy, 2009). Many investigations were carried out where several bacterial strains were found to degrade and assimilate lignin. Bacterial strains of *Bacillus pumilus* and *Bacillus atrophaeus* have been utilised for the production of lignin degrading enzymes such as laccase (Huang et al., 2013). Bacterial degradation of lignin has been reported including erosion, tunnelling and cavity formation.

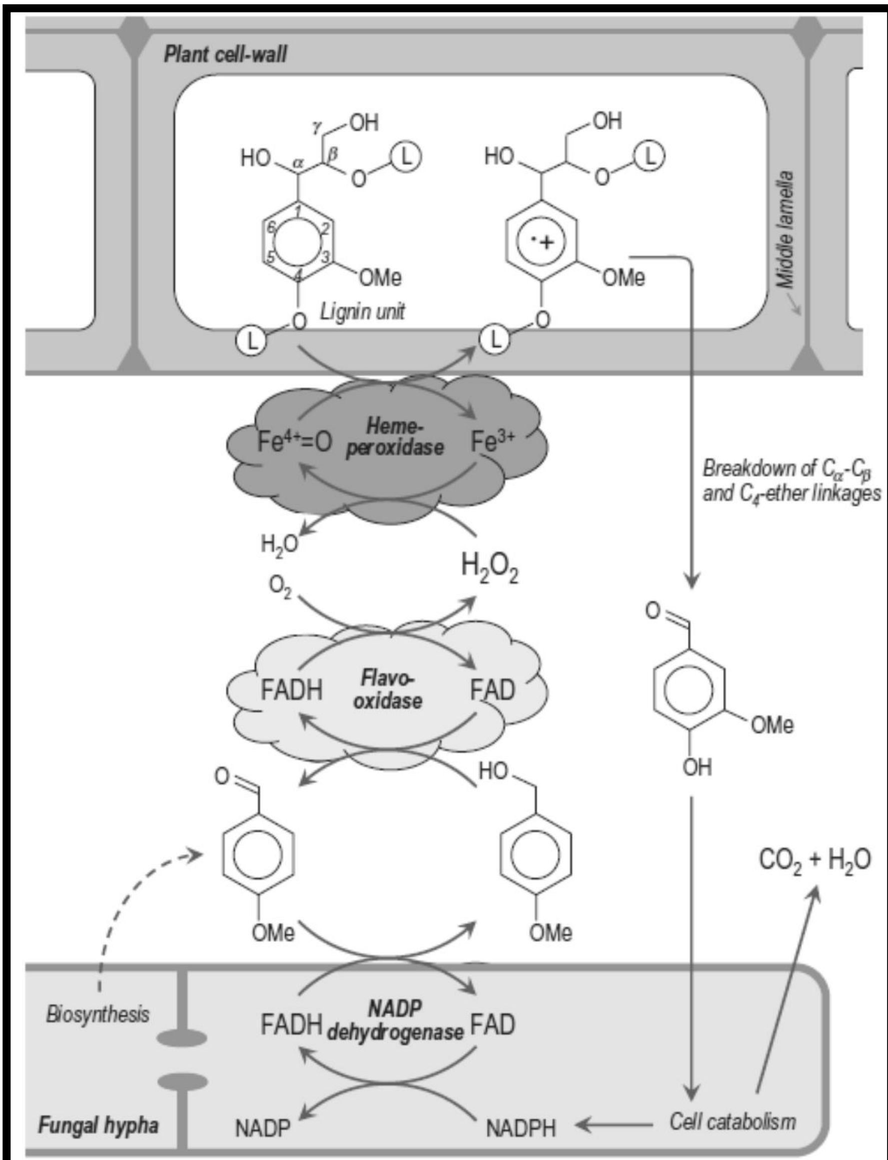
Degradation of lignin up to 20-30% in culture media, by *Pseudomonas* and *Flavobacterium* has been achieved (Sorensen, 1962). A mixed culture of three bacteria *Bacillus* sp., *Paenibacillus* and *Aneurinibacillus aneurinilyticus* reduced kraft lignin (KL) by 40% while individually they degraded the KL by 37%, 33% and 30% respectively (Chandra et al., 2007). At the same time *Aneurinibacillus aneurinilyticus* could degrade lignin in 6 days up to 43% in another experiment by Raj et al. (2010). Similarly, Chandra and Abhisshek (2011) recently reported that mixed cultures of *Citrobacter* sp. could increase the reduction in colour in black liquor to 79% and the reduction in lignin to 60% after just 6 days of incubation. Perhaps mixed cultures could serve to improve the activities and collective effects of our isolates on lignin modification and carbohydrate degradation lending greater lignocellulosic abilities (Maki et al., 2012). Members of *Pseudomonas sp*. were suggested to have ligninolytic activities as some *Pseudomonas sp*. have recently been described for their abilities to degrade dyes such as Malachite Green and Direct Orange 39 (Orange TGLL) with lignases as peroxidases (Du et al., 2011; Jadhav et al., 2010).

Non-filamentous bacteria usually mineralize less than 10% of lignin preparations and can degrade only the low-molecular weight part of lignin as well as degradation products of lignin. Thus, they may play some role in final mineralization of lignin. Among these eubacteria, *Pseudomonas* spp. are the most efficient degraders. Filamentous bacteria belonging to the genus *Streptomyces* are well known degraders of lignin (Ball et al., 1989) and could mineralize up to 15% of labeled lignins but usually much less. Typically, *Streptomyces* spp. solubilises part of lignin, and the end product is water-soluble acid perceptible polymeric lignin (Hatakka, 2001). In an experiment, Berrocal et al. (1997) found *Streptomyces cyaneus* CECT 3335 solubilizing 45% of the ^{14}C (lignin) fraction and mineralizing 3% of the label in 21 days. The reference species *S. viridosporus* solubilized 59% and mineralized 4.5% of the same substrate. The presence of phenol oxidase and peroxidase was found in *S. cyaneus*, the former activity being 100 times greater as determined by the oxidation of ABTS and 2, 4-dichlorophenol, respectively.

BIOCHEMICAL MECHANISM OF LIGNIN DEGRADATION

Lignolytic microbes have developed a unique strategy to handle lignin degradation based on unspecific one-electron oxidation of the benzenic rings in the different lignin substructures by extracellular haemperoxidases acting synergistically with peroxide-generating oxidases. These peroxidases possess two outstanding characteristics: (i) they have unusually high redox potential due to haem pocket architecture that enables oxidation of non-phenolic aromatic rings and (ii) they are able to generate a protein oxidizer by electron transfer to the haem cofactor forming a catalytic tryptophanyl-free radical at the protein surface, where it can interact with the bulky lignin polymer.

In *Pleurotus* species, the enzymatic degradation of plant cell-wall lignin occurs with contribution of extracellular flavooxidases (such as AAO) generating hydrogen peroxide during redox cycling of non-phenolic aromatic aldehydes (such as the fungal metabolite *p*-anisaldehyde) with participation of intracellular aryl-aldehyde dehydrogenase. Peroxidase one-electron oxidation of lignin units (the key step in the degradative process) results in an unstable cation radical that experiences different reactions including breakdown of Cα–Cβ and C4–ether linkages releasing the corresponding aromatic aldehydes (vanillin in the case of guaiacyl units) that can be intracellularly mineralized. In the case of *P. chrysosporium* LiP, lignin attack requires the presence of veratryl alcohol, probably as an enzyme-bound mediator, and hydrogen peroxide is mainly generated by glyoxal oxidase (Figure 3) (Duenas and Martinez, 2009).



(Courtesy: Duenas and Martinez, 2009)

Figure 3. Pictorial scheme of the enzymatic degradation of plant cell-wall lignin by *Pleurotus* (L-containing circles represent the remaining lignin polymer).

Under aerobic conditions, high molecular weight lignin molecules are converted into oligolignols which are then might be subject to anaerobic biodegradation and transformed into lignin monomers (Nickelsen, 1993). Highest mineralization of lignin was obtained at 100% oxygen demonstrating that lignin degradation is oxidative process (Hatakka, 2001). Even though lignin biodegradation is accepted as an aerobic process, some authors have reported that anaerobic microorganisms in the rumen may alter, if not partially degrade, portions of lignified plant cells (Akin, 1980). Reports indicate that cleavage of the most common inter monomeric bond in natural lignin is possible in the absence of molecular oxygen (Colberg and Young, 1982; Zeikus et al. 1982). However the conditions under which monomeric lignin is formed are not well understood (Nickelsen, 1993).

Lignin biodegradation by white-rot fungi is an oxidative process in which phenol oxidases are the key enzymes (Kuhad et al., 1997; Rabinovich et al., 2004). Out of these, lignin peroxidases (EC 1.11.1.14) (LiP), manganese peroxidases (EC 1.11.1.13) (MnP) and laccases (EC 1.10.3.2) from white-rot fungi (especially *Botrytis cinerea*, *P. chrysosporium*, *Stropharia coronilla*, *P. ostreatus* and *Trametes versicolor*) have been studied (Howard et al., 2003; Martinez et al., 2004). LiP and MnP oxidize the substrate by two consecutive one-electron oxidation steps with intermediate cation radical formation. LiP degrades non-phenolic lignin units (up to 90% of the polymer), whereas MnP generates Mn3+ which acts as a diffusible oxidizer on phenolic or non-phenolic lignin units via lipid peroxidation reactions. Laccases are blue-copper phenoloxidases that catalyze the one-electron oxidation mainly of phenolic compounds and non-phenolics in the presence of mediators. The phenolic nucleus is oxidized by removal of one electron, generating phenoxy-free-radical products, which can lead to polymer cleavage (Perez et al., 2002; Bugg et al., 2011; DeSouza, 2013). Recently, other enzymes involved in lignin degradation have been reported. These include arylalcohol oxidase (AAO) described in *Pleurotus eryngii* (Guillén et al., 1992) and other fungi and *P. chrysosporium* glyoxal oxidase (Kersten and Cullen, 2007). Fungal aryl-alcohol dehydrogenases (AAD) and quinone reductases (QR) are also involved in lignin degradation (Sanchez, 2009). Since lignin is composed of phenylpropanoid units, then the oxidative breakdown of lignin could potentially release low molecular weight such as β-Aryl ether, biphenyls, diarylpropanes, ferulic acid, protocatechuic acids etc. Alone by *Phanerochaete chrysosporium*, 28 low molecular weight fragments are produced, 10 of which were aromatic carboxylic acids and a further 13 of which were acyclic 2,4-hexadiene-1,6-dioic acids resulting from oxidative ring cleavage. The in vivo breakdown pathway of oxidised lignin fragments were rarely studied and mainly elucidated in bacteria (Bugg et al., 2011).

Degradation of lignin in Actinomycetes takes place by the production of extracellular peroxidises e.g., lignin peroxidase-type enzyme. *Streptomyces* sp. EC1 produces peroxidise and cell-bound demethylase requiring H_2O_2 and Mn_2. Both of which are produced at relatively high levels in the presence of Kraft lignin or wheat straw, while protochatechuate 3,4-dioxygenase and b-carboxymuconate decarboxylase activity were less induced (Hatakka, 2001).

MICROBIAL DEGRADATION OF HEMICELLULOSES

When subjected to microbial decomposition, hemicelluloses degrade initially at faster rate and are first hydrolyzed to their component sugars and uronic acids. The hydrolysis is brought about by number of hemicellulolytic enzymes known as "hemicellulases" excreted by the microorganisms. On hydrolysis hemicelluloses are converted into soluble monosaccharide/sugars (eg. xylose, arabinose, galactose and mannose) which are further convened to organic acids, alcohols, CO_2 and H_2O where as uronic acids are broken down to pentoses and CO_2 (agriinfo). Aerobic and anaerobic, fungal and bacterial communities are involved in the degradation of hemicelluloses and its various forms like Glucan, Xylan, Mannan, Arabinan, Galactan etc. Biodegradation of hemicelluloses requires enzyme activities that remove nonxylose substituents from the xylan backbone in addition to endoxylanases and β-xylosidases. Xylan is aspecific hemicelluloses which is mainly degraded by fungi at preiliminary stage and at elevated temperature (up to 65^0C) the activity is carried out by thermophilic bacteria (Rajvaidya and Markandey, 2006). The presence of microorganisms that are able to degrade xylan was reported over 100 years ago. Large number of actinomycetes and *Bacillus* species isolated from soils and compost can degrade xylans. Xylanolytic microorganisms grown under natural conditions produce both cellulolytic and xylanolytic enzymes to efficiently degrade plant cell walls. However, some of them, like *Fibrobacter* and *Ruminococcus*, are not able to grow on xylose, the degradation end-product of xylan (Schyns, 1997). Harada et al. (2008) isolated a bacterium *Paenibacillus* sp. strain HC1 which exhibited xylanase activity and could degrade rice bran hemicelluloses to use it as the sole source of carbon (Harada et al., 2008). Mannan which is composed mannose in polymeric combination is readily degraded by *Bacillus*, *Vibrio*, *Aspergillus*, *Trichoderma*, *Penicillium*, *Rhizopus* and many more. Similarly Galactan serves as a prime carbon source for many *Basidiomycetes* such as *Aspergillus*, *Humicola*, *Zygorhynchus* etc. (Rajvaidya and Markandey, 2006). Bacteria play a role in both aerobic and anaerobic degradation of hemicelluloses. Some plant pathogenic *Pseudomonas* sp., *Xanthomonas alfalfae*, and *Achromobacter* species have been isolated that also produce hemicellulases as a part of their enzyme system (Schyns, 1997). Activities removing o-acetyl, arabinose, cinnamic acid-based esters, and uronic acid substituents occurred in*Streptomyces olivochromogenes*, *Aspergillus niger*, and *Schizophyllum commune*. 4-O-Methylglucuronidase was coinduced with other substituent-hydrolyzing enzymes when appropriate lignocellulosic materials were provided (Johnson et al., 1989). When grown on wheat straw, the brown rot fungus *Piptoporus betulinus* cultures caused 65% loss of dry mass within 98 days and exhibited endo-1,4-*β*-glucanase (EG), endo-1,4-*β*-xylanase, endo-1,4-*β*-mannanase, 1,4-*β*-glucosidase (BG), 1,4-*β*-xylosidase, 1,4-*β*-mannosidase and cellobiohydrolase activities (Valaskova and Baldrian, 2006).

Anaerobic degradation of hemicellulose occurs in a variety of anaerobic biota, such as manure, compost, sludges of waste water treatment plants and marine or freshwater sediments. In addition, the hydrolysis of xylan by anaerobic microorganisms present in the rumen and gastro-intestinal tract plays an essential role in the nutrition of herbivorous animals. Their xylanolytic activities play an important role in the overall rate of degradation of plant cell wall material in the rumen system. *Ruminococcus, Butyhvibrio, Bacteroides, Prevotella* and *Fibrobacter* species are rumen bacteria with xylanolytic activities. Several xylanolytic enzymes produced by these organisms have been identified and characterized and the genes of some xylanolytic enzymes from *Fibrobacter succinogenes, Prevotella (Bacteroides) ruminicola, Butyrivibrio fibrisolvens, Ruminococcus albus*, and *Ruminococcus flavefaciens* were recently cloned (Schyns, 1997). Different aerobic and facultatively anaerobic bacteria and yeasts were found to be present in termite gut which degraded hemicelluloses like xylan, arabinogalactan and carboxymethylcellulose. Among them gram-positive isolates belonged to the genera *Bacillus*, *Paenibacillus*, *Streptomyce*s group, while the Gram-negative strains were assigned to the genera *Pseudomonas*, *Acinetobacter*, *Ochrobactrum* and to genera belonging to the family Enterobacteriaceae (Schafer et al., 1996).

BIOCHEMICAL MECHANISM

Hemicelluloses are biodegraded to monomeric sugars and acetic acid. It is first degraded or hydrolyzed by means of extracellulose enzymes and then utilised by microbes. Three different types of enzymes may be involved: a. End-oenzymes which randomly cleave the building blocks of polymer, b. Exo-enzymes which cleave either a single dimer or monomer from the end of polysachharide chain and c. Enzymes collectively known as glycosidase (Rajvaidya and Markandey, 2006). Complete degradation of Xylan, the main carbohydrate found in hemicelluloses, requires the cooperative action of a variety of hydrolytic enzymes. The endo-1,4-β-xylanase generates oligosaccharides from the cleavage of xylan and 1,4-β-xylosidase works on xylan oligosaccharides, producing xylose (Jeffries, 1994; DeSouza, 2013). In addition, hemicellulose biodegradation needs accessory enzymes such as xylan esterases, ferulic and *p*-coumaric esterases, α-l-arabinofuranosidases, and α-4-O-methyl glucuronosidases acting synergistically to efficiently hydrolyze wood xylans and mannans. In the case of O-acetyl-4-O-methylglucuronxylan, one of the most common hemicelluloses, four different enzymes are required degradation: endo-1, 4-β-xylanase (endoxylanase), acetyl esterase, α-glucuronidase and β-xylosidase. The degradation of O-acetylgalactoglucomanann starts with rupture of the polymer by endomannases. Acetylglucomannan esterases remove acetyl groups and α-galactosidases eliminate galactose residues. Finally, β-mannosidase and b-glycosidase break down the endomannases-generated oligomers β-1, 4 bonds (Perez et al., 2002; Saha, 2003).

MICROBIAL DEGRADATION OF PECTIN

Microbial ability to degrade pectin was reported in several studies. Many microorganisms viz.,bacteria, yeast, fungi could produce pectinases (Geetha et al., 2012). The ability of yeasts to decompose pectic substances has revealed the presence of an exocellular polygalacturonase active at pH 4.5 in a marine strain of *Cryptococcus laurentii*, a strain of *Cryptococcus albidus*. a culture of *Pullularia pullulans*, and two unidentified yeast cultures. The capacity to decompose pectin has also been shown in four strains of *Cryptococcus diffluens*, Saccharomyces *kluyveri*. one each of *Crypococus laurentii* (terrestrial), *Pullularia* sp., *Sacclraromyces bayanus*, *Saccharomyces carfsbergensis*, *Saccharomyces cceevisiae* (mutant strain), *Saccharomyces marxianus Saccharomyces turbidans* (Bilimoria and Bhat, 1961). Benoit et al. (2012) found fungal species *A. niger*, *A. oryzae*, *A. nidulans* and *B. cinerea* were having good growth on pectin from soy, apple, citrus and sugar beet and on four structural elements of pectin. In that experiment the presence or absence of pectinolytic genes in the fungal genome clearly correlates with their ability to degrade pectins (Benoit et al., 2012). Endo-polygalacturonase and pectin esterase enzymes were synthesized in pectate-based culture filtrates and ripe strawberries, artificially inoculated with *Rhizopus stolonifer, Rhizopus sexualis, Mucor piriformis* or *Aureobasidium pullulans* depicting their pectinolytic activity (Archer, 1979).

Among the various pectinase, bacterial extracellular pectinase are the most significant, compared with animal, Plants, viruses and fungal extracellular pectinase. Extracellular pectinase produced by *Bacillus* and *cocci* species are of main interest from a biotechnological perspective and are not only in scientific fields of protein chemistry and protein engineering but also in applied fields such as foods, pharmaceutical and paper industries. Soil bacteria *Bacillus licheniformis, Bacillus cerus,* and *Staphylococcus aureus* exhibited high pectinase activity on pectinase agar plates (Nagaraju and Divakar, 2013). Other *Bacillus* species were also reported to exhibit higher pectinolytic activity which used citrus pectin as sole source of carbon. Those bacteria performed well at pH of 6.0 – 7.0, optimum temperatures between 45^{o}C and 55ºC (Soares, 1999).

BIOCHEMICAL MECHANISM

As observed for cellulose and hemicellulose, degradation of pectins also requires a set of hydrolytic enzymes to degrade completely the polymer. Glycoside hydrolases (GHs) and polysaccharide lyases (PLs) are the two classes of hydrolytic enzymes required for pectin backbone degradation. The GHs involved in pectin backbone degradation include endo and exo-polygalacturonases, which cleave the backbone of smooth regions, while the intricate hairy regions are further degraded by endo and exo-rhamnogalacturonases, xylogalacturonases, α-rhamnosidases, unsaturated glucuronyl hydrolases, and unsaturated rhamnogalacturonan hydrolases (van den Brink and de Vries, 2011). Endo and exo-polygalacturonases are able to cleave α-1, 4-glycosidic bonds of α-galacturonic acids. Rhamnogalacturonases cleave α-1, 2-glycosidic bonds between D-galacturonic acid and L-rhamnose residues in the hairy region of the pectin backbone (DeSouza, 2013; Prade et al., 1999).

Microbial Degradation through Composting

Major agricultural wastes are decomposed through composting, a process involving complex ecosystem with many interacting factors in which biodegradable organic wastes are stabilized and converted by the action of microorganisms (Yu et al., 2007). The microbes utilize decomposable organic both as an energy and food source. The composting process converts a material with potential odor and other nuisance problems into a stabilized product that is reasonably odor and pathogen free. In addition, the volume and weight of the composted product is less than that of the original raw waste because composting converts much of the carbonaceous material to gaseous carbon dioxide (Sadik et al., 2010).

The composting process involves three phases and uses diverse microflora such as bacteria, fungi and mesophilic (*Streptomyces rectus*) and thermophilic *Actinomycetes* (*Actinobifida chromogena* (*Thermomonospora fusca*) *Microbispora* (*Thermopolyspora*) *bispora, Therinomnonospora curvata, Thermoactinomyces* sp.) eventually converting organic waste to humus. During the first phase there is an increase in carbon dioxide along with the temperature. The substrate is reduced due to the degradation of sugar and proteins by the action of mesophilic organisms. The second phase leads to an increase of the temperature in the compost piles from 45°C to approximately 70°C and the mesophiles are replaced by thermophiles. Large numbers of pathogenic individuals are degraded during this time. The third phase begins with the decrease of temperature of the compost pile (Pan et al., 2012). The microbial community and their enzymatic activity evolved according to various stages during composting. An analysis of microbial community using 16S RNA sequence data by He et al. (2013) deciphered that *rcobacter* spp. and *Marinospirillum* spp. were the dominant species prior to composting, whereas *Thermotogae* spp. became more strongly represented as the composting process proceeded. *Bacillus* and *Cohnella* spp. were featured at various phases. Similarly Chandana et al. (2013) found the number of mesophilic bacteria increased rapidly in first ten days of composting which was 1.7- 2.84 × 109 cfu g-1. However, the thermophilic bacteria were dominant from 11–32 days of composting, with count in between 108 to107 cfu g-1. Finally, mesophilic population stabilized between 106 to 105 cfu g-1 during the cooling and maturation phase (33–40 days). In that study the majority of the bacterial isolates (78.8%) were affiliated with *Firmicutes* (especially the genera *Bacillus sp*., *Terribacillus sp*. and *Lysinibacillus sp.* etc.), whereas only 9.1, 6.1 and 6.1% of bacterial isolates were affiliated to the members of γ-proteobacteria, β-proteobacteria and actinobacteria respectively. Apart from spore forming *Bacilli* other genera in the compost were *Staphylococcus*, *Serratia*, *Klebsiella*, *Enterobacter*, *Microbactrium*, *Kocuria*, *Acidovorax* and *Comamonas*. Interestingly, genera like *Kocuria*, *Microbacterium*, *Acidovorax* and *Teribacillus* have been reported for the first time from the compost population from agricultural by-products (Chandana et al., 2013). Correlation analysis showed that the diversity of the microbial community was positively correlated with the compost pH, its total nitrogen level, its carbon-to-nitrogen ratio and the activity of protease and negatively correlated with its organic carbon content and seed germination indices (He et al., 2013). Characterizing and quantifying the enzymatic activity along with microbial number and types during composting can reflect the dynamics of the composting process in terms of the decomposition of organic matter and nitrogen transformations, and may provide information about the maturity of the composted product (Devi et al., 2009).

CONCLUSION

As the demand for food increases the amount of agro wastes will also increase in the environment due to increase in agricultural activities. The proper disposal strategies of these wastes should be framed to minimise environmental pollution. Microorganisms are the key entities for the degradation and decomposition of agricultural waste residues. These can degrade different components of agro wastes which are mainly composed of plant residues or they can specifically degrade a particular component like cellulose, hemicelluloses, lignin, pectin etc.

The above discussions clearly elaborated the efficiency of bacteria, fungi and actinomycetes to degrade different agro wastes hence these should be exploited properly.

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Chapter 5

SEWAGE FED AQUACULTURE: A VIABLE PROPOSITION FOR FISH PRODUCTION THROUGH NUTRIENTS RECOVERY AND WATER CONSERVATION, IN EFFECT OF ABATING AQUATIC POLLUTION

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ABSTRACT

In the context of freshwater scarcity, technological intervention is essentially required for recycling of wastewater, through the formulation of well planned strategies. Sewage fed aquaculture is one such strategy established as a reliable system with proven techniques by which used water is reused. In this system, sewage is treated by the technique known as 'Bio-remediation' through application of macrophytes. This is a unique method through which a suitable amount of nutrients is recovered from sewage water and then utilized under controlled manner in the purpose of fish production through fertilization of pond water. The nutrient load contained in raw sewage water could, otherwise, be wasted. That 1.0 L of sewage water is utilized as estimated to produce 0.309 g of fish biomass through nutrients recovery as much as 0.05 g in form of N and P is an effective procedure, apart from 0.99 L of water restoration. Utilization of such bio-remedied water requires specific technology in promoting fish culture, including pond preparation, species selection, maintenance of species ratio, stocking density, farming method and harvest. In India, intervention of proper technological support revealed the fish production achieved up to 5250 kg ha^{-1} yr^{-1}, which has been better yield than that in feed based culture practice. However, fish reared in a sewage fed system is a concern to many with regard to its safe consumption because of the contaminant load contained in sewage water. The amount of contaminants that cause aquatic pollution can be reduced through 'Biological treatment' to the extent by which it is to be safe for its use in aquaculture systems. Besides, the traverse of the long distance of raw sewage from its origin to culture ponds via stabilized pond leads to reduce the amount of contaminants,

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including heavy metals and microbial load. Also, sewage concentration made less than 50% becomes weak to be the least toxic or to have no toxic effect on organisms and in turn be suitable for fish rearing. In the context of global warming, using sewage water through technological intervention is a unique approach which needs to be encouraged.

Keywords: Sewage, phyto-remediation, aquaculture, fish production, pollution

INTRODUCTION

Water is finite in quantity and tangible in nature with unequally distributed in both space and time (Sharma and Bharat, 2009). However, fresh water is considered a renewable resource, though its supply is steadily decreasing due to population growth, human intervention and climate change (Sarala et al., 2009). Utilization of freshwater for agriculture is essential. Demand for fresh water is likely to increase with the increase of food grain production, apart from the essential need for drinking purpose for people and livestock. In India, water which is already a scarce resource will become further scarcer in the foreseeable future (Sharma and Bharat, 2009), with per capita water availability predicted to reduce as low as 1401 m^3/yr in 2025 from 1820-1902m^3/yr in 2001 (Gupta and Deshpande, 2004; Sharma, 2005). Freshwater resource which is essential for sustenance of human civilization needs to be managed properly through the formulation of well planned strategy. It appears certain that freshwater allocation for aquaculture will be further limited. In this respect, recycling of already used water like domestic sewage has immense relevance in utilization for the purpose of fish production through nutrients recovery as well as water conservation. This is possible in an aquaculture system subjected to implementation of appropriate technological intervention. A huge amount of nutrients contained in domestic sewage which, otherwise, creates water pollution is recycled among biotic and abiotic components to increase water productivity in aquaculture systems. It may thus contribute towards nutritional security through utilization of misplaced nutrients as part of efficient resource allocation to make ecosystem vibrant as well as proper functioning (Dasgupta et al., 2010; Chakrabarti et al., 2011). Subsequently, it is the rational management of water conservation with effect of reduction of water pollution.

It appears that about 20 liters of waste water in the form of domestic sewage are released per person day $^{-1}$ in and around Kolkata. In the towns and cities of India, total annual discharge of sewage contains 90 mt of nitrogen, 32 mt of phosphorus and 55 mt of potassium valued Rs. 6.10 crores (Chakrabarti et al., 2011). This huge amount of nutrients contained in sewage needs to be undergone through the proper treatment procedure before the entire system is to be viable as practicable source of livelihood as well as income generation. Several studies conducted in India and elsewhere (Olah et al., 1986; Jhingran and Ghosh, 1988; Ghosh et al., 1988; Jhingran, 1991; Jana, 1998; Ghosh et al., 1999; Datta et al., 2000; Ayyappan, 2000; Chakrabarty, 2002; Bhakta and Jana, 2006; Bunting, 2007; Mukherjee and Jana, 2007 and Jena et al., 2010) infirmed that utilization efficiency of sewage water reuse has been beneficial for the production of fish crop safe for human consumption (Rajan et al., 1995; Bhowmik et al., 1997). In this context, we are presenting a review of the experience of Central Institute of Freshwater Aquaculture (CIFA) during the past three decades in sewage fed aquaculture critically looking at the whole system of sewage utilization and nutrients recovery from a unit of sewage water utilization, at the effect of the rational yield of fish biomass and water conservation as well.

2. Technology of Sewage Treatment

2.1. Genesis

Sewage-fed fishery operated in water bodies locally christened as 'Bheries' in East Kolkata Wetlands (EKW) of West Bengal, India are considered to be a potential model of sewage fed aquaculture (Edwards, 1992, 2008; Jana and Datta, 1996; Jana, 1998, Nandeesha, 2002). Fish farmers around the periphery of the east Kolkata city in India developed a technique of using a huge amount of domestic sewage for fish culture almost a century ago, in the 1930s. This sewage based system of fish production is considered to be unique and is the largest operational method in the world to convert waste into resourceful wealth to meet the growing demand for fish in this highly populated city (Nandeesha, 2002). Besides, an integrated approach of farming system is undertaken for raising crops comprising agri-horti-aquaculture on pond embankment. The total area utilized under this unique system of culture covered around 12,000 ha initially, which has presently come down nearly 4000 ha due to sprawling of the city.

2.2. Characteristic of Domestic Sewage

Composition and concentration of domestic sewage vary greatly depending mainly on the lifestyle and habits of users who release it after sanitary use. Organic compounds, detergents, mineral elements, along with a scanty amount of pharmaceuticals, hormones and other materials are found in domestic sewage. Generally raw sewage comprises about 99% water and rest form solid material, including organic solids (70%) of which protein 65%, carbohydrate 25% and fat 10%. Inorganic solids (30%) include silt and minerals (Chakrabarti et al., 2011). However, characteristic of domestic sewage which is eventually used in aquaculture depends upon the source of waste, the process of its treatment, dilution, distance it runs in an aquaculture system in which it is used. Even its quality varies with the season it is generated. All these factors lead to the degree of suitability by which use of sewage will become purposeful for its utilization in fish culture. There is a great variation of physico-chemical parameters of sewage in different sources in sewage fed system operated in WAD, CIFA. The raw, treated and moderate sewage, with average value of selective parameters (Table-1), may be considered as strong, medium and weak sewage respectively (Jana, 1998). The primary treated sewage is undertaken rational treatment unless it is found suitable to be incorporated in culture ponds with an appropriate ratio of freshwater and sewage water as 4:1or 3:1.

Table 1. Selective physico-chemical parameters of sewage in different forms

Sl.No.	Parameter	Raw sewage	Treated sewage	Moderate sewage	Pond water
1	pH	6.1	7.0	7.5	7.5
2	Total solids	720	250	200	80
3	Total Alkalinity	300	240	190	170
4	Total nitrogen	25	15	10	1.0
5	P_2O_5	08	05	02	0.15
6	BOD_5	400	200	80-100	10-18

Value in mg l^{-1}.

Besides, quality of sewage also depends on the amount of microbes present in it and their degree of adversity in human health. The most common microbes present in raw sewage include *Escherichia coli*, *Staphylococcus aureus*, *S. epidermidis*, etc. with the Maximum Probable Number/100 ml (MPN) as recorded as 125×10^6, $41.6\times10^5$and 16.28×10^4, respectively in raw sewage, treated sewage and fish reared pond. Protozoa, helminthes, fungi and virus are also noticed and even quite a large number of bacteria remain present, though most of them are non-pathogenic (Bhowmik et al., 1997).

2.3. Treatment of Sewage

Sewage water needs to be treated before being utilized in culture ponds. Methodical treatments (Fig. 1) reduce the organic load and BOD (Biochemical Oxygen Demand) - the determining factor of the degree of quality of sewage, resulting in an increase of DO (dissolved oxygen) and pH. Standard limit of both the factors is essential for survival & growth of fish. Our Research Centre at Rahara has been practicing sewage treatment through its own technological intervention. The farm receives primary treated sewage through 1.5 km long pipeline by gravity from Titaghar Sewage Treatment Plant under Kolkata Municipal Water Sanitation Authority (KMWSA), wherein raw sewage is mechanically treated. A required amount of primary treated sewage after its discharge of Sewage Treatment Plant (STP) is stored in a circular cemented pit constructed in the farm. A critical monitoring with repeated chemical analyses of available treated sewage is done at this juncture in view of whether it is to be incorporated into rearing ponds directly or kept putting in stabilized ponds temporarily or undergone repeated biological treatments following respective steps 1-6 mentioned in Fig. 1. The parameters of treated sewage need to be leveled down at par with that of moderate sewage suitable for incorporation in rearing ponds. In this respect, aquatic macrophytes are known to be reliable as highly efficient to reduce organic load markedly (Gersberg et al., 1986; Naskar et al., 1986; Mann and Bavor, 1993) due to their rapid growth to high biomass by accumulating nutrients. They can also tolerate nutrient laden wastewater while growing. Their operational ease of harvesting and processing afterwards as fish feed due to low fiber content (Naskar et al., 1986; Abdalla et al., 1987; Rodrigues and Oliveria, 1987; Santos et al., 1987) are some additional benefits. This kind of treatment may be considered a comprehensive solution for the treatment of domestic sewage (Oron et al., 1988; Hammouda et al., 1995; Jena et al., 2010).

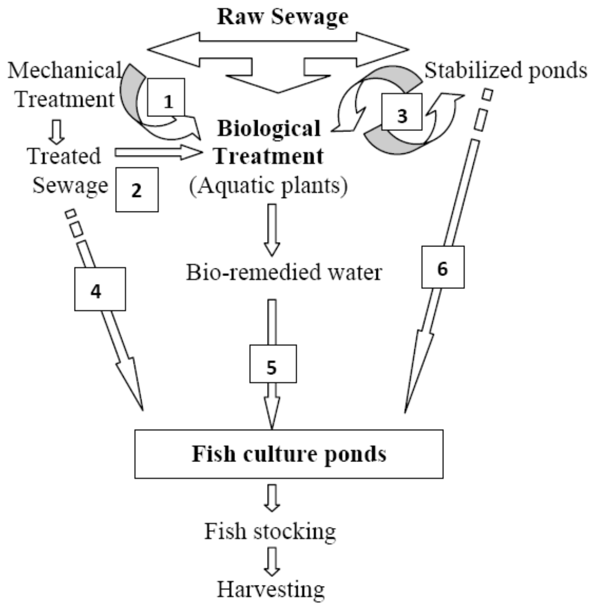

Figure 1. General treatment procedures of sewage and its use in aquaculture.

2.3.1. Methods of Bioremediation

Several natural, innovative, alternate approaches of biological treatment of wastewater have been evaluated over the years for their economic viability, operational ease and system sustainability (Edwards, 1992, 2008; Jana and Datta, 1996; Jana, 1998, Ayyappan, 2000; Jena et al., 2010). Evidently, different stages of biological treatment using Duckweeds are considered to be a viable technology of sewage treatment (Oron et al., 1986; Oron et al., 1988; Oron, 1994; Ayyappan, 2000, Jena et al., 2010) in the perspective of sustainable aquaculture: Sewage water is allowed by gravity to pass through linearly constructed and interconnected ponds covered with respective duckweeds starting from *Spirodella polyrrhiza*, then *Lemna minor,* to *Wolfia arrhiza* based on their higher efficacy of nutrients accumulation. Retention period of sewage in each Duckweeds covered pond may be for 3-5 days, depending on the quantity of organic load contained in particular sewage, with provision of intermittent staggering walls in order to allow longer traverse distance and much retention time of the sewage. Once the pond is fully covered with weed mat, 50% of the same was harvested, allowing growing space for residual weeds (Ayyappan, 2000; Jena et al., 2010). Parameters like BOD, total ammonia nitrogen, phosphate went down by 80%, 88% and 71%, respectively, while those of DO and pH increased to 10% and 1705% (Fig. 2). Treatment of sewage depends upon factors like retention time, temperature (Alaerts et al., 1996), pH, solar radiation and presence of predators (El-Hamouri et al., 1995; Fallowfield et al., 1996; Rangeby et al., 1996). Reduction of microbial load was also remarkably higher (Jena et al., 2010) as total coliform and faecal coliform went down by 87% and 92.5% respectively. Reduction of population of pathogenic bacteria may occur (Bhowmik et al., 1997) as much as low due to provision of staggering walls in the duckweed ponds. Increasing the traversing distance may affect the reduction of coliform bacteria to the extent of 60-99.9% of aerated lagoon system (Fernandez et al., 1992), 93-94% through facultative, aerobic and oxidative pond system (Neiwoloak and Tucholski, 1995). Garcia and Becares (1997) reported the removals of total coliforms, faecal coliforms with a hydraulic retention time of three days while treating with macrophytes. Increasing biomass of macrophytes leads to reduce the BOD load along with nitrogen and phosphorus amount proportionately and enhances the amount of DO and pH conducive to fish growth and development (Fig. 3). Sometimes, reduction of microbial load of sewage may not go down desirable level since surface water is fully covered with Duckweeds, preventing sunlight penetration into the water column (Gijzen and Veenstra, 2000).

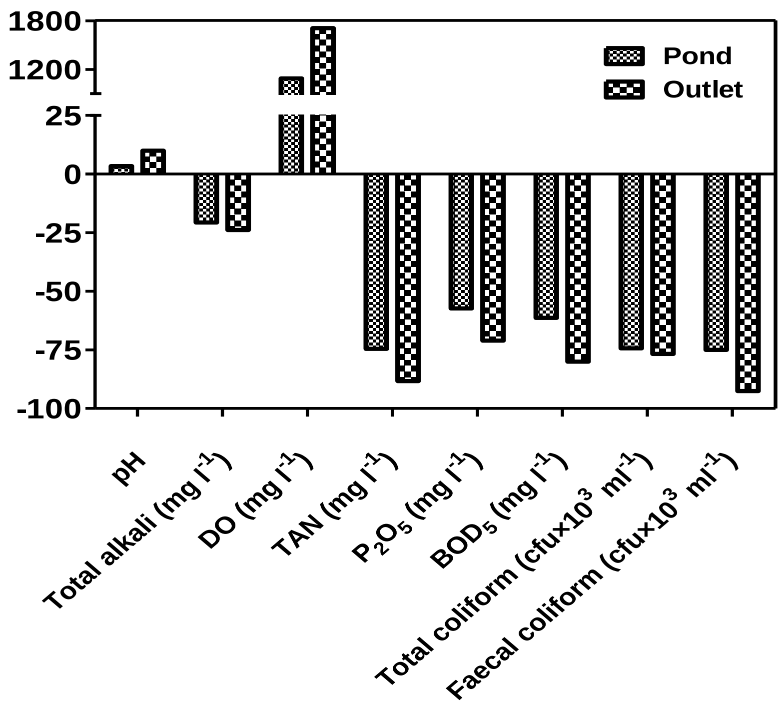

Figure 2. Sewage water become conducive through biological treatemnt (reference data set: inlet).

2.4. Nutrients Recovery

Incorporation of sewage in fish culture ponds facilitates to increase the productivity of water body and make aquatic system vibrant by addition of required nutrients (Ghosh et al., 1980; Jana, 1998; Jena et al., 2010). A comparison of water qualities between a sewage-fed and a commonly fertilized fish pond has shown that the former exhibited significantly higher values of BOD, N, P, and Cl^{-1}, while early morning pH value was lower in this pond (Chattopadhyay et al., 1990). CIFA with its long experience on utilization of domestic sewage reaches an estimate (Fig. 4) that one liter of sewage may generate average amount of 0.05g nutrients in form of N & P and conserve 99% of water. The intake of 1.0 liter sewage effluent has been found to yield an average amount of 0.30g biomass in form of fish reared in such sewage fed water bodies. Potentiality of sewage is quantified in terms of nutrients added as fertilizer input in culture system. Calculation shows that 469 kg ha^{-1} of nitrogen and 62.7 kg ha^{-1} of phosphorus in the form of ammonia nitrogen (NH_4-N) and phosphate (P_2O_5) were available as fertilizer when an amount of 10.538 × 10^3 m^3 ha^{-1} sewage water added in sewage fed pond system for 8.5 months culture period (Fig. 5). This amount of sewage which was considered as essential fertilizer input for optimal production of fish in such system has been found yielding 3254 kg of fish/ha (Datta et al., 2000). Other sewage fed systems of the world are reported to apply nearly three folds more sewage @ 150 m^3 ha^{-1} day^{-1}, with particular reference to Hungary (Olah, 1990). Zhang (1990) reported that rate of intake in China varied from season to season ranging from 1-5% of the volume of pond water at an interval of 4-15 days. Usually during winter, some farms used to take wastewater as basal fertilizer @ 10% or more of the total pond water volume. Potentiality of sewage depends upon the condition of particular water body in which sewage is required as fertilizer input conducive to fish growth and survival.

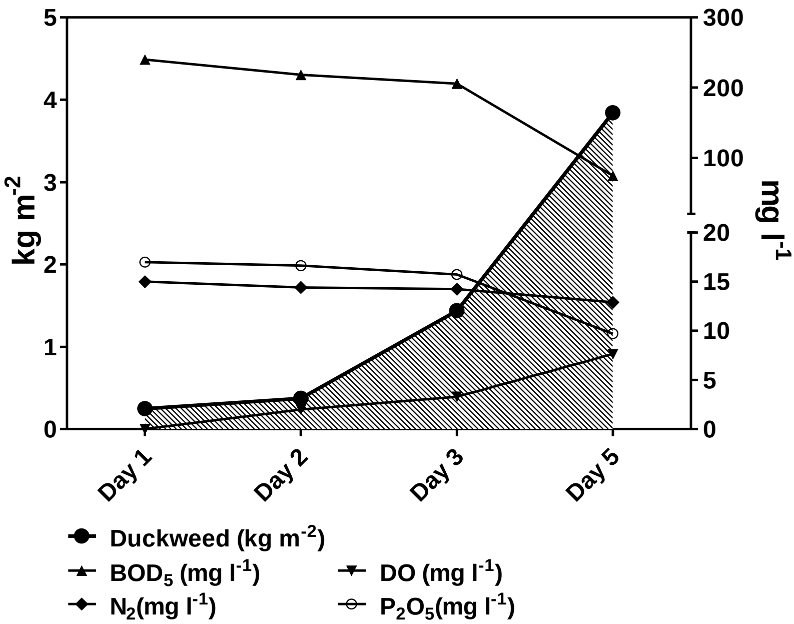

Figure 3. Increase of Duckweed biomass improving water quality.

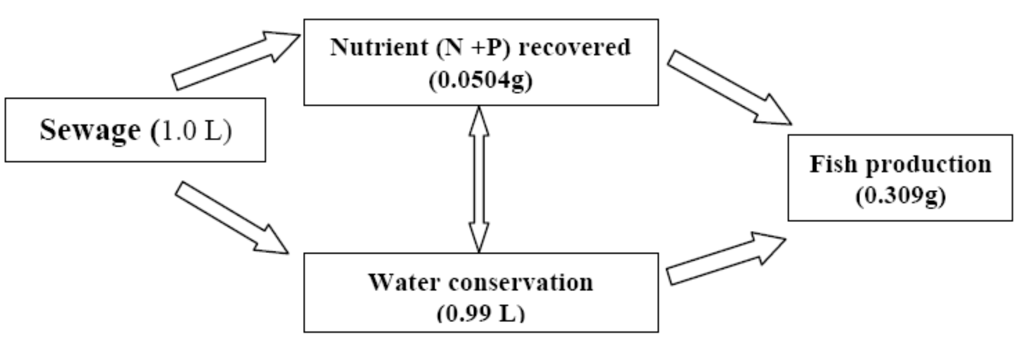

Figure 4. Nutrients recovery along with water conservation and fish production from utilization of unit volume of sewage.

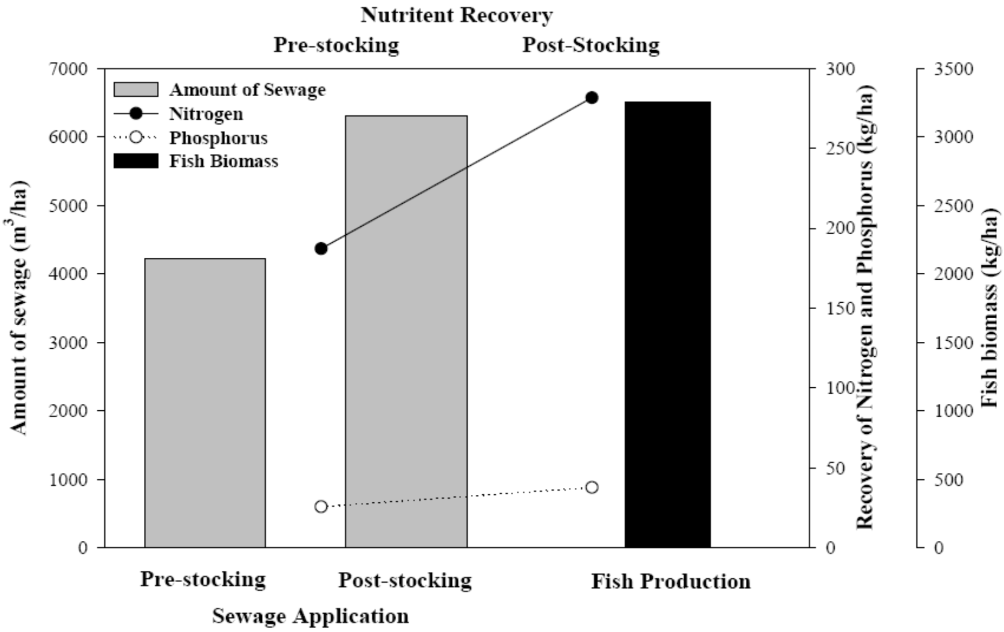

Figure 5. Amount of sewage application responsible for substantial growth of fish biomass through nutrients recovery per hacter-m water body.

2.5. Pond Productivity

Gross Primary Productivity (GPP) and Net Primary Productivity (NPP) are two important parameters indicating the condition of pond water in the purpose of aquaculture activity. An estimate of GPP recorded in sewage fed farm pond accounts the range of 650-850 mg C m^{-3} h^{-1}, considered to be optimal productive pond, with NPP ranges between 250-450 mg C m^{-3} h^{-1} (Saha et al., 2001). This condition favours aquaculture production in respect of fish growth and development due to sufficient amount of DO in pond water. Nutrient enriched sewage water facilitates high production of plankton population which is considered to be the base of trophic level of food chain (Bhowmik et al., 1993; Boyd and Tucker, 1998). Phytoplankton production increases rapidly due to fertilization through sewage, constituting about 80% of the total plankton population, with range recorded between 65,000-1,20,000 nos /l. and zooplankton being about 20%, with the range between 20,000-45,000 nos /l. Three types of algal groups are found prevalent in sewage fed water; green algae of which is the most dominating one compared to blue green algae and diatoms. Diatoms represent as the major constituent of benthic community. Phytoplankton population in sewage fed ponds dominates over zooplankton during most of the culture period. Zooplankton appears to be visible distinctly with dominance of Cladocerons, when density of phytoplankton population declines.

3. TECHNOLOGY OF FISH CULTURE

3.1. Pond Preparation

Aquaculture practice essentially requires pond preparation for production of desirable yields (Edwards, 1992, 2008; Nandeesha, 2002; Datta et al., 2000; Jena et al., 2010). Depth of the pond is one of the important criteria while managing pond preparation. Sewage-fed fish farm is of little less depth than that of normal freshwater fish farm as sewage tends to increase the turbidity of water (Datta et al., 2000). During pond preparation water is pumped out and bottom is exposed to sunlight for complete drying for first 2-3 weeks before initiation of culture. Removal of pond water also eradicates the unwanted fishes and also makes de-siltation easy (Datta et al., 2000; Nandeesha, 2002). After drying, tillering the bottom soil up to 6-10cm through raking, followed by application of lime @ 400-500 kg ha^{-1} is undertaken as essential steps for maintenance of proper oxidation, desired level of pH, eradication of parasite and their cysts, and removal of obnoxious gases from the bottom soil (Nandeesha, 2002). Sometimes, mahua oil cake @ 2000-2500 kg ha^{-1} is applied for provision of developing suitable environment to increase the availability of food and space necessary for culture species to be stocked in pond prior to intake of sewage (Datta et al., 2000).

3.2. Intake of Sewage Effluent and Manuring of Pond

Proper pond management considers efficient use of nutrient dynamics in soil & water, and their interactions to activate functioning of microbes in these processes for maintaining sustainability and ecological efficiency of this kind of ecosystem (Chakrabarti et al., 2011). The main factor which governs the use of sewage water for effective fertilization of fish culture pond necessitates the optimal requirement of wastewater loading rate. The proper amount of sewage intake allows the pond ecosystem to remain aerobic throughout the day and night during the culture period. Generally BOD level of raw domestic sewage remains an amount of 400 mg l^{-1}, which comes down in the range of 40-132 mg l^{-1} through simple sedimentation process (Edwards, 2008; Jana 1998; Datta et al., 2000; Chakrabarti et al., 2011). The resultant sewage is known as primary treated sewage water. Parameters of pond water determine the amount of primary treated sewage required for its incorporation in culture system. Some factors like green color of water, low transparency, and minimal surfacing of fish at dawn to gulp air are indicative of hygienic pond condition (Chakrabarti et al., 2011). Chattopadhyay et al. (1988) reported maintenance of pond water BOD at a range of 10-20 mg l^{-1} to be helpful in maintaining an aerobic condition as well as good productivity level in sewage-fed fish ponds. No supplementary feeding or pond fertilizer or pond fertilization is required during the culture period since supply of sewage effluents adds nutrients which stimulate the production of fish food organisms in the culture system. Sewage fed ponds are required with supply of sewage continuously or periodically depending on pond area, water volume, availability of wastewater, seasonal condition with regard to temperature fluctuations and dilution of pond water due to monsoon rains. The topography of the site should ideally be flat or gently sloping towards the outlet so that treated wastewater can be taken into pond preferably by gravitation to minimize the running expenses (Nandeesha, 2002). In such systems freshwater supply to the pond is also required in addition to freshwater already stored in the pond. Production of fish biomass is related to the amount of sewage intake. Optimal rate of sewage intake is essential to achieve desirable scale of fish yield. Evidently low production of fish biomass was recorded from 20 to 5 kg d^{-1} ha^{-1}, when the amount of sewage intake was higher than 250 $m^3 d^{-1} ha^{-1}$ and below than 150 m^3 d^{-1} ha^{-1} (Olah, 1990). A study revealed that net production of 1440-2400 kg ha^{-1} was achieved in Hungary when the ponds were fed with 150 m^3 $d^{-1} ha^{-1}$ of sewage water (Olah, 1990). Low intake of sewage creates nutrient deficiency whereas higher intake than required amount develops depletion of DO leading to mass mortality.

3.3. Selection of Species

Judicious selection of fish species is important one among other factors for sewage fed aquaculture. The species which are selected in sewage fed aquaculture are capable of suitably adapted for effective utilization of natural food organisms (Nandeesha, 2002; Datta et al., 2000; Chakrabarti et al., 2011). Four main categories of fishes are selected in preference to the feeding habits: herbivorous, detritus feeder, carnivorous, and omnivorous. Herbivorous feed on microalgae, including phytoplankton. They are the most efficient users of energy as directly feeding on producers. Detritus feeders feed on dead organisms, organic and decayed matters at the bottom of the pond, their food consist of plants and animal organic matter. Carnivorous fish feed on small size organisms including annelid larvae, insect larvae, crustaceans, and molluscs. Omnivorous species feed on both plant and animal matter (Chakrabarti et al. 2011). In sewage-fed ponds, Indian carps, catfish and prawn have been successfully tested to grow, with variable graded levels of sewage concentration tolerable from species to species. Graded levels of sewage also vary with varied age groups of same species with their tolerable limits. Indian major carps, namely catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), reba bata (*Cirrhinus reba)* and bata (*Labeo bata*) are reared in sewage fed ponds (Ghosh et al., 1980; Ghosh et al., 1988; Ghosh et al., 1999). Even minor carp like mourala (*Amblypharyngodon mola*) is also reared in monoculture system in shallow water body added with low concentration of primary treated sewage in Rahara fish farm. Exotic carps are also grown. Silver carp (*Hypopthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) are reared along with indigenous species with suitable ratio of stocking density in maintenance of individual niche practiced to pond culture system (Ghosh et al., 1988; Datta et al., 2000). Efficiency of tilapias (*Oreochromis niloticus* and *O. mossambicus*) to tolerate considerable limit of sewage concentration has made them attractive to farmers for their acceptance as one significant component in sewage fed culture system. Both the species of tilapia constitute 5-30% of species stocked as seen in different sewage fed farms. Some farmers stock Pangas (*Pangasianodon hypophthalmus)* in the condition of comparatively high organic loaded water since they are biologically hard organism with capacity of survival at low DO level, even up to 3.0 mg l^{-1}. Indian catfish like *C. batracus* and *H. fossilis* are also standardized growing in sewage fed aquaculture system of shallow water body during rainy season as a part of integrated culture practice in paddy cum fish culture system considering their increasing price as well as consumers' preference. Some are attempting to culture high value species like giant freshwater prawn, *Macrobrachium rosenbergii* and their considerable yield in this system may be attractive to farmers.

3.4. Stocking Density

Stocking density of fish seeds is an important factor for operating sewage fed aquaculture (Nandeesha, 2002; Datta et al., 2000; Edwards, 2008; Chakrabarti et al., 2011). Usually, fingerlings of 10-15 g in size are stocked in sewage fed pond culture (Datta et al., 2000), which is comparatively bigger size stocked than was undertaken in freshwater pond as usual practice. This procedure varies depending on fish seed availability, their necessary size tolerable to sewage fed water, carrying capacity of the pond, physico-chemical parameters of pond water, food organisms available in pond, and above all the bio-geographical conditions of the species (Nandeesha, 2002; Edwards, 2008). Generally it ranges between 5000 and 10,000 fingerlings ha^{-1}. Fishes are grown mostly on the natural food growing in the pond. Sewage is drawn at regular interval @ 2-3% of the total volume of pond water. Stocking of fingerlings @ 8000 fingerlings ha^{-1} takes place during the months of September – August, with species combination and ratio as *Catla catla* (catla) 20%, *Labeo rohita* (rohu) 25%, *Cirrhinus mrigala* (mrigal) 20%, *Hypopthalmichthys molitrix* (silvercarp) 20%, *Ctenopharyngodon idella* (grass carp) 5% and *Cyprinus carpio* var. *communis* (common carp) 10% (Datta et al., 2000). A dip treatment of potassium permanganate solution was given to the fingerlings before releasing them into ponds as remedial measure against infection since they are grown in sewage fed water.

3.5. Farming Methods

Farming method of carp culture comprises rotational cropping system: fish are stocked and harvested throughout the culture period leading to periodical stocking and regular harvest (Nandeesha, 2002). This culture practice is responsive to market demand and economically viable to farming community. Composite fish culture is practised to harness the potentiality of entire pond ecosystem and to make the pond environment sustainable (Ghosh et al., 1999; Datta et al., 2000; Chakrabarti et al., 2011). In this practice, right species with proper size suitable to sewage fed culture system is required, apart from maintaining distinct ration considering their appropriate niche. Catla, rohu, and mrigal are first choice, along with bata. Exotic species is combined in composite culture practice and in such case silver carp is the proper candidate to maintain pond ecosystem when algal bloom is excessive. Release of silver carp is advisable because it can control algal bloom otherwise pond water may suffer from depletion of DO due to uncontrolled algal growth. Algal bloom in sewage fed pond water may trigger any time because of excess amount of organic load through sewage intake. Tilapia is suitable for monoculture practice; even in high organically loaded pond tilapia is able to survive and is beneficial to farmers. In some farms, both bata (*Labeo bata*) and reba (*Cirrhinus reba*) are cultured as a part of monoculture practice without addition of supplementary feed and their growth is found remarkable (Ghosh et al., 1985; Ghosh et al., 1999). The photosynthetic activity in the pond is the basis for biological purification of the sewage. Once the water turns completely green, stocking of fish is initiated. Before stocking, fish are kept in hapas in the pond to test pond condition through survival. If the results are positive, large scale stocking is undertaken. Fish stocking takes place several times in a year depending on the intensity of operation.

3.6. Fish Rearing, Production and Harvest

Sewage fed fish farm of CIFA has standardized fish production by efficient utilization of primary treated sewage with yield of 4603.9 kg $ha^{-1}yr^{-1}$ (Datta et al., 2000). Six species were reared comprising catla (*Catla catla)*, rohu (*Labeo rohita)*, and mrigal (*Cirrhinus mrigala*) from Indian major carp, and silver carp (*Hypopthalmichthys molitrix)*, common carp (*Cyprinus carpio)* and grass carp *(Ctenopharyngodon idella)* from exotic carp for 8.5 months. Some selective farming parameters such as growth rate (g day^{-1}), survival (%), net weight (g), gross production (kg $ha^{-1}yr^{-1}$) and net production (kg ha^{-1} yr^{-1}) were obtained through intermittent sampling during culture practice (Fig. 6a,b,c and d). Silver carp exhibited significantly ($p<0.05$) both the highest growth rate (3.81±0.67) and net weight (927.2±219.22) among others. Grass carp followed the 2nd step, with significantly ($p<0.05$) higher growth rate (2.73±0.67) and net weight (680.3±205.4) than that of the rest species. Other species exhibited growth rate as ranging between 0.96±0.89-1.63±0.19 and net weight between 299.7±26.27-354.5±43.1, without significant ($p>0.05$) difference. Intake of sewage was found to be conducive since survival (%) of fish ranged between 71.3±9.3-97.2±2.45. Silver carp was found to be the most preferable species since it significantly ($p<0.05$) exhibited the highest gross (1435.73±281) and net (1411.4±281.38) production, followed by rohu with gross (616.58 ± 33.64) and net production (574.92±34.93).

Fish production recorded from sewage fed farming was found better than that in feed based culture practice, with same species combination and duration. Feed based culture practice exhibited 15.15% lower production (Fig. 7) compared to sewage fed system, though no significant ($p>0.05$) difference was recorded (Datta et al., 2000). Freshwater composite carp culture system using feed, lime, fertilizers, etc. in different regions of India revealed the production in the range of 1988.44 to 5250.66 kg $ha^{-1}yr^{-1}$ (Routh and Tripathy, 1988) which is quite compatible to this low-cost production system (Roy and Ghosh, 1987; Rai et al., 1996). Jhingran and Ghosh (1990) reported the higher fish production in the range of 5002.4 to 6791.0 kg ha^{-1} yr^{-1}, with stocking density ranging between 10,000 - 24000 ha^{-1} in sewage-fed ponds. Zhang (1990) documented net fish production of 700-11963 kg ha^{-1} yr^{-1} from waste-fed aquaculture in China.

Optimal growth of fish was checked through repeated netting. Harvest takes place twice a month to obtain table size fish for consumption after three months from stocking fingerlings. After completion of one cycle of harvest, fishes are restocked @ 1.0 kg of fingerlings for every five kg of fish harvested. Fishes are left undisturbed for the subsequent fortnight and harvesting will start again after that period. Harvested fish usually undergo rechecking with certain features: coming out of foul smell, faded lusture of skin, dull appearance and slow movement. Harvested fish with these features need to be kept in depuration for 24-72 hours in freshwater ponds. Depuration helps to bring fish having freshness as to be attractive to consumers.

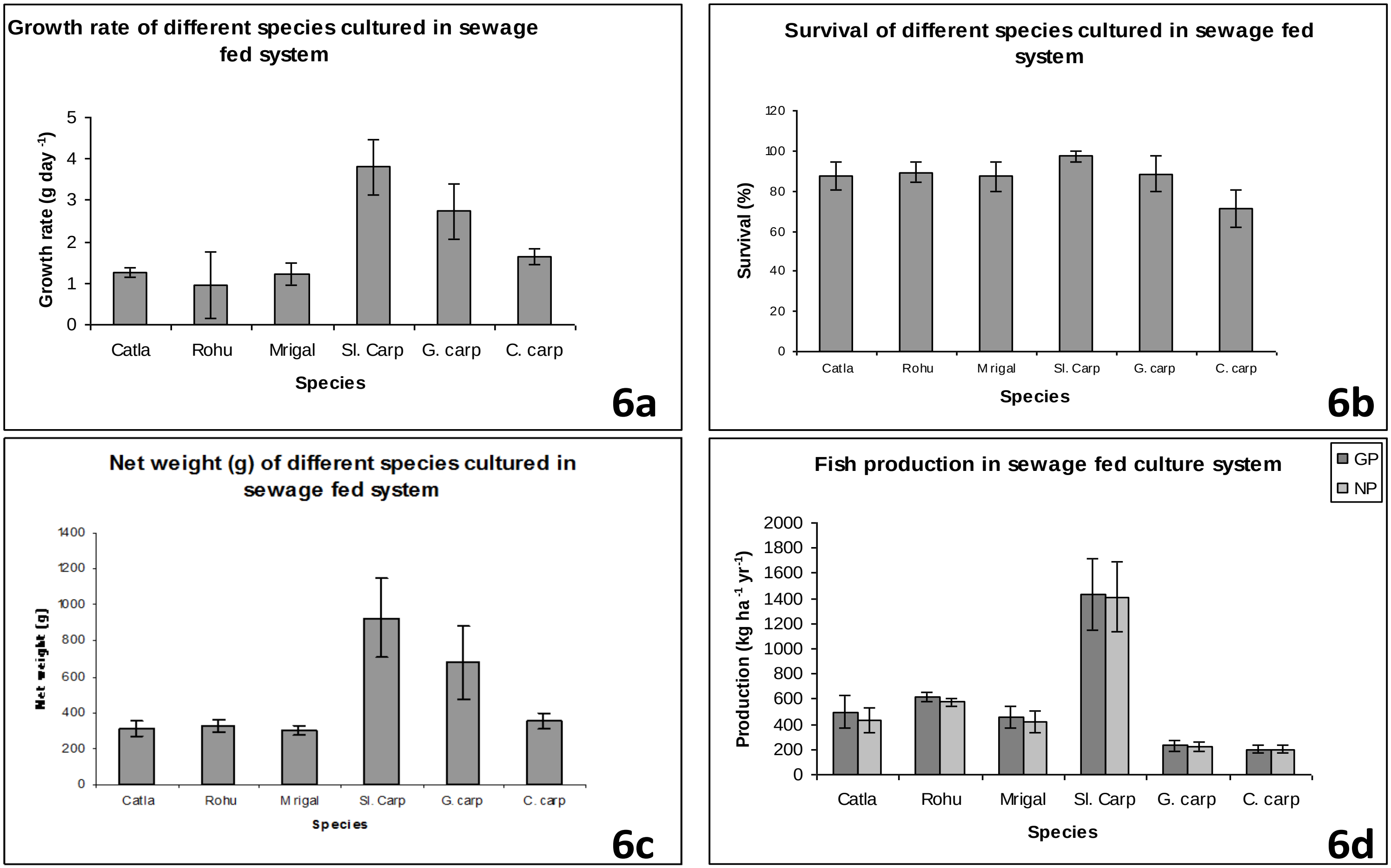

Figure 6a,b,c,d. Different fish species cultured in sewage fed aquaculture.

4. Technology of Abating Aquatic Pollution

Some factors like microbial load, BOD level, and concentration of heavy metals cause to develop aquatic pollution. The concentration of these contaminants is taken into account while fish are reared in sewage fed aquaculture.

4.1. Microbial Load

Microbial load was studied in different sewage fed systems right from raw sewage to diluted ones. In the raw sewage, different strains of microbial load (cfu × $100ml^{-1}$) was recorded (Bhowmik et al., 1997; Bhowmik et al. 2000) in the following range: total coliform, 30.0-180.0 × 10^6; faecal coliforms, 6.2-59.0 ×10^6; faecal streptococci, 61.0-110×10^6; total pseudomonads, 35.0- 120×10^6 and heterotrophic bacteria (cfu × ml^{-1}), 9.0-13.8×10^4. However, in sewage fed fish pond these bacterial loads exhibited very low amount (cfu × $100ml^{-1}$) in the range: total coliforms, 16.28-47.4 × 10^4; faecal coliforms, 1.3-10.29 ×10^4; faecal streptococci, 3.0-9.3×10^4; total pseudomonads, 49.7-92.0×10^4 and heterotrophic bacteria (cfu × ml^{-1}), 7.8-24×10^4. The traverse of long distance of raw sewage from its source to the eventual destination of sewage fed pond via stabilized pond leads to reduce the microbial load. Sometimes, stabilized ponds covered with macrophytes are found much effective for reducing microbial load. Microbial population examined from different organs such as slime, gills, gut and muscle of sewage fed fish exhibits the following trend as gut > slime > gills > muscle. Different strains of bacterial load (cfu × $100ml^{-1}$) as total coliforms, faecal coliforms, faecal streptococci, total pseudomonads and heterotrophic bacteria (cfu × ml^{-1}) have been recorded as 1.8-5.4×10^2, nil, 1.7×10^3-9.3×10^2, 2.6-4.1×10^2 and 2.4-4.4×10^3 respectively from 1.0g of muscle (Bhowmik et al., 2000). Fish muscle used for human consumption exhibits minimal microbial load or nil as considered to be safe for human health; even though this negligible amount may be killed by culinary process. Gut (digestive tract) contains maximum amount of microbial load. All these, except muscle, are not usually used as food for human consumption and eliminated during processing. Methods like long traverse of raw sewage, phyto-remediation, and short deposition in stabilized pond are altogether beneficial to lead to the changes of bacterial flora from predominant population to suitable limit found not to be harmful in fish culture (Buras, 1988). More and above, Biological Treatment System through phyto-remediation, involving different ponds in the series could reduce microbial load up to 99% as reported by others (Krishnamoorthi et al., 1982; Hejkal et al., 1983; Mills et al., 1992; Rangeby et al., 1996; Bhowmik et al., 1997; Bhowmik et al., 2000; Jena et al., 2010). The reduction of bacterial load in stabilization and facultative ponds, in turn, facilitates to the growth of different phytoplankton and consequently oxygenation takes place from their photosynthesis (Ghosh et al., 1988).

4.2. Heavy Metals Concentration

Heavy metals of domestic sewage is examined repeatedly and found to remain below safe level. Organic substances are used as domestic needs and so concentration of organic matters is the main components of sewage water. The analysis showed that different concentration (ppm) of heavy metals like Mn, Cu, Cr, Pb and Zn vary in the range of 0.05-5.0, apart from As (ppb) and Cd (ppb) with < 1.234 in primary treated sewage water. When muscle and gills of four species such as catla, rohu, mrigal and bata are examined, concentration (ppm) of Mn, Cu, Cr, Pb and Zn remained in the range between 0.063-2.092 in gills and 0.015-0.109 in muscles against the permissible limit in the rage of 0.2-5.0. Primary treated sewage water contained very negligible amounts of heavy metals below permissible limit. Fish reared in such sewage fed water is found safe for human consumption. More and above, phyto-remediation has been tested as proven technique to accumulate heavy metals contained in sewage water, if any (CIFA Annual report, 2004; Sengupta et al., 2012; Raychoudhury et al., 2007). Nevertheless, fish reared in sewage fed water bodies needs to be undergone repeated verification through analyses that can ensure its acceptability to consumers in respect of safety issue.

4.3. Toxicity

Different graded levels of sewage were tested for their suitability for fish rearing through bioassay trial. LC_5, LC_{50} and LC_{95} values of wastewater for the fish on 96h of observation were 24.35%, 52.88% and 70.0%, respectively. Toxic effects of wastewater on fish *Oreochromis mossambicus* occurred within the 48h. Acute toxicity values of domestic wastewater were measured using different species of fish as test organisms at different times (Gill and Toor, 1975; Akolkar and Belsare, 1981; Sarker et al., 1993 and Bhowmik et al., 1995). The 96 h LC_{50} for fry of *Cyprinus carpio* was 34% in domestic wastewater (Ghosh et al., 1985). Lower range of LC_{50} values (31-33%) was reported for fry of *Labeo rohita* (Sarker et al., 1993) which indicated that *Oreochromis mossambicus* is comparatively more resistant than other species of fish. Domestic sewage (secondary treated) was found to be nontoxic to *Leuciscus idesmelontus* at 50% of the sewage concentration (Becker-Birch and Hevenmeister, 1980). Fish exposed to 70% dilutions (70% sewage, 30% tap water) lost body balance within 6h. Movement of fish was reduced and later lethargic movements with frequent surfacing were noticed, which might be due to high respiratory stress. Survival of IMC fingerlings exposed to 96h LC_{50} was found to be about 50% (Mandal, unpublished). When, fingerlings were exposed to 40% concentration, survival record was 80% for 96h observation (Mandal et al., 2013). Factors like maturity, physiology and genetic configuration vary species wise to respond toxicity; nevertheless, less than 50% dilution of primary treated sewage was suitable for rearing fish subject to incorporation of moderate sewage effluent. The fish exposed to such sewage water was found active and behaved normally.

4.4. Acceptability

Characteristic of sewage is dynamic in nature. Materials used for domestic purposes are the key factors to determine the quality of sewage. The fish culture system generally uses sewage water only when it is treated properly through mechanical, biological or other reliable means, and always avoids the direct use of raw sewage. Though there are fears about the safety of the fish grown in sewage fed systems, it is the general belief in Kolkata that the fish grown in sewage tastes better (Chakrabarti et al., 2011). This has been partly attributed to the good nutrition obtained from the rich plankton growth in ponds. Evidently, live fish which contributes about 20% of the total marketed fish in and around Kolkata city are brought from different sewage fed fish farm, major contribution from sewage fed East Kolkata Wetlands. However, there are some recommended guidelines with regard to use of sewage in the purpose of fish production for human consumption (WHO,1989; Pullin et al., 1992): (i) minimum retention time of 8-10 days for raw sewage, (ii) suspension of wastewater loading for 2 weeks prior to fish harvest, (iii) tentative maximum critical density of 10^5 total bacteria ml^{-1} in wastewater-fed fish pond water, with < 50 number of bacteria g^{-1} of fish muscle and no *Salmonella*, (iv) absence of viable treatment eggs in fish ponds, (iv) holding fish for a few hours in freshwater to facilitate evacuation of gut contents and (v) good hygiene in handling and processing, including evisceration, washing and cooking well.

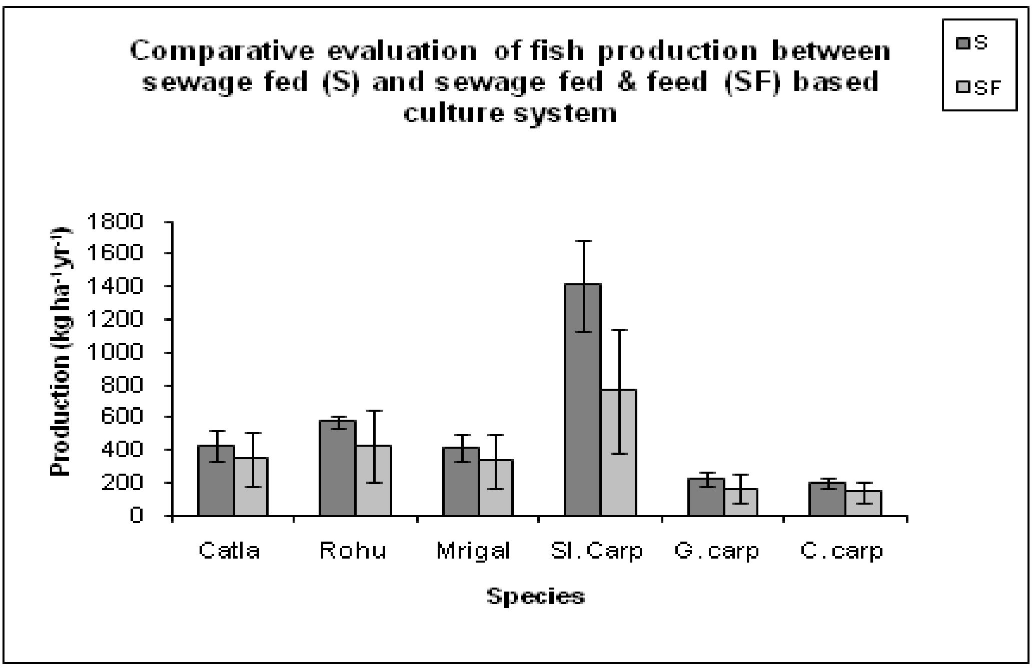

Figure 7. Comparative evaluation of fish production in sewage fed and feed based culture practice.

CONCLUSION

In the context of global warming and climate change, there is increasing concern about freshwater shortage. The practice of using sewage water for aquaculture in urban fringe (peri-urban) areas needs to be encouraged. Increasing the productivity of water used for aquaculture has high relevance to provide nutritional as well as livelihood security for the farmers. Recycle of treated sewage effluent in aquaculture has been tested as an instance to enhance water productivity of the system. The water quality and fish rearing practices in such water are evaluated considering environmental issues as a major concern. Biological productivity in the form of fish biomass in sewage fed aquaculture serves two important purposes: (i) efficient nutrient utilization in view of gross primary productivity (GPP) through phytoplankton production, and (ii) water conservation in the context of increasing freshwater scarcity. Wastewater-fed aquaculture is an age-old practice for social benefit of treating and recycling wastewater with the principal objective of assimilation of dissolved nutrients, which otherwise would have been wasted, into biomass which is consumable for all the living beings directly or indirectly.

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Chapter 6

WASTE TO ENERGY TECHNOLOGY

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ABSTRACT

Solid waste management in cities is an integral part of urban and environment management. Municipal solid waste management, like most of other infrastructural services has come under great stress. In the low priority areas, solid waste management was never taken up seriously by public, concerned agencies or authorities but now the piled up waste is threatening our health and environment. The waste management technology is capable of maintaining both environmental and energy concerns because it has dual benefits of pollution control as well as energy production. Waste incineration is defined as the combustion of solid and liquid waste in controlled combustion facilities. It is one of the waste treatment processes that involve the combustion of organic substances contained in waste materials. Incineration converts the waste into ash, flue gas and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned before they are dispersed into the atmosphere. The heat generated by incineration can be used to generate electric power.

Keywords: Solid waste management, waste incineration, energy generation, sustainable development

INTRODUCTION

Solid waste management in cities is an integral part of urban and environment management. Municipal solid waste management, like most of other infrastructural services has come under great stress. In the low priority areas, solid waste management was never

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taken up seriously by public, concerned agencies or authorities but now the piled up waste is threatening our health and environment. The waste management technology is capable of maintaining both environmental and energy concerns because it has dual benefits of pollution control as well as energy production. Established treatment technologies for Solid Waste are

1. Incineration/Combustion
2. Gasification
3. Pyrolysis
4. Composting
5. Biomethanation
6. Recycling
7. Land filling

1. INCINERATION/COMBUSTION

Waste incineration is defined as the combustion of solid and liquid waste in controlled combustion facilities. It is one of the waste treatment processes that involve the combustion of organic substances contained in waste materials. Incineration converts the waste into ash, flue gas and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned before they are dispersed into the atmosphere. The heat generated by incineration can be used to generate electric power.

Fundamentally, incineration is the process of direct burning of wastes in the presence of excess air (oxygen) at temperature of about 800˚C and above, liberating heat energy, inert gases and ash. Net energy yield depends upon the density and composition of the waste; relative percentage of moisture and inert materials, which add to the heat loss; ignition temperature; size and shape of the constituents; design of the combustion system. In general about 65 to 80% of the energy content of the organic matter can be recovered as heat energy, which can be utilized either for direct thermal applications, or for producing power via steam turbine generators. The combustion temperatures of conventional incinerators vary from 760˚C - 870˚C, which is insufficient to burn or even melt glass. To avoid the deficiencies of conventional incinerators, modern incinerators utilize higher temperatures (1650˚C) using supplementary fuel. This reduces waste volume up to 97% and converts metal & glass to ash.

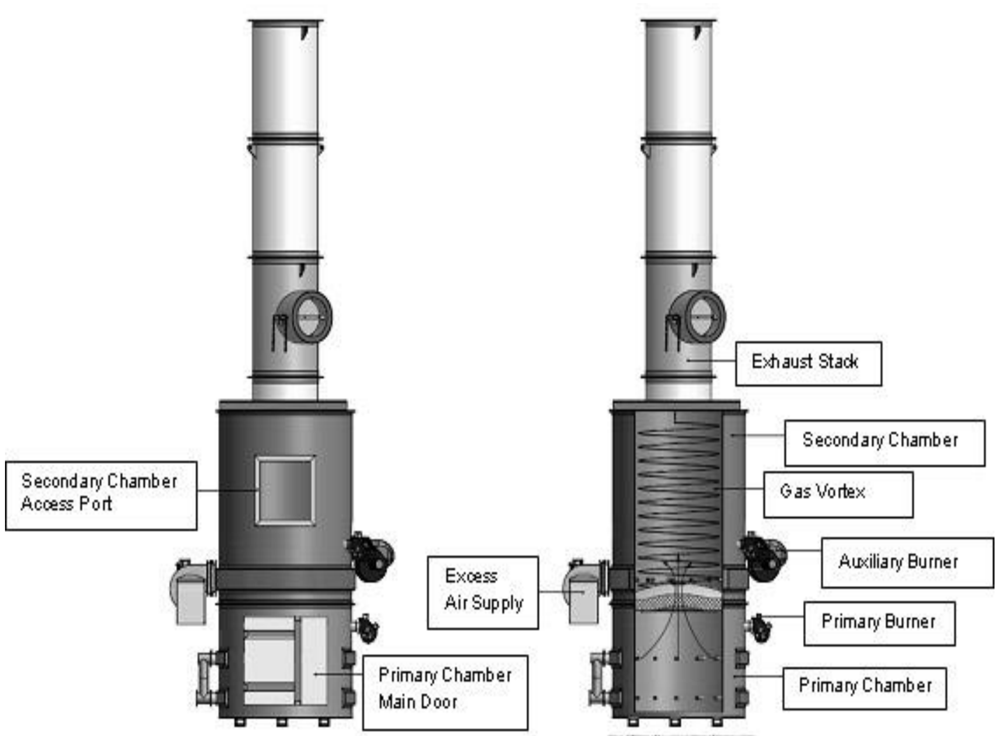
1.1. Types of Incinerators

There are two main types of waste incinerators:

1. Batch incinerators
2. Continuous incinerators

1.1.1. Batch Incinerators

Batch waste incinerators, as name indicate are loaded at a time with waste through an open door which is then closed before the waste is ignited. The door remains closed until the ash residues remaining on the hearth have cooled and can be safely removed. The duration of a batch waste incinerator cycle is measured in hours. Batch waste incinerators have two zones. In first zone the waste is ignited and mixed with air to promote combustion, and in second zone additional air is added to complete the combustion process. Its size ranges from 50 to 3,000 kg of waste/batch (Figure 1).



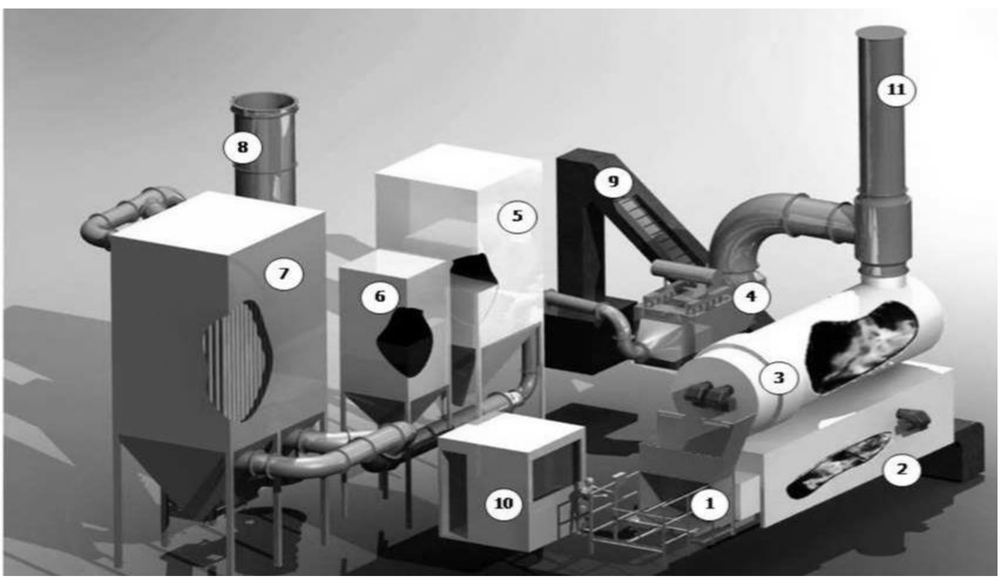
Source: Chandler, A.J., 2007.

Figure 1. Batch type waste incinerators.

1.1.2. Continuously Operated Incinerators

It receives fresh waste and discharge ash residues periodically throughout their operation, which can last from weeks to months. The waste is charged into the continuous-feed primary chamber after it has achieved operating temperature of 600°C to 850°C; however loading method of MSW and configuration of incinerators may vary. In general, the waste is delivered to the system using a mechanical material handling device such as a skid steer loader or conveyor and a waste charge or load is deposited in the first stage of the system via a hopper. The hopper directs waste towards the primary chamber where it is moved by a mechanical ram or piston that will push the waste into the system. Mainly it has 11 major components (Figure 2).

The Operator is isolated from the heat of the process by a guillotine style door. Although this process may be highly automated, generally the operator is required to be available to load the ram hopper every 20 minutes during the burn cycle. Within the primary chamber, the waste bed moves slowly along the stepped floor grate as it is pushed by a series of transfer rams. In this phase, which takes up to 6 hours, the solid waste is transformed into a gas that is drawn into the secondary chamber. Sterile non-combustible material such as metals, glass and a non-toxic, non-leaching ash that is safe for disposal on-site remains in the continuous-feed primary chamber. In the secondary chamber, the combustible gases are exposed to a highly-oxygenated and extremely turbulent environment for a minimum of a 2 second retention time at a temperature of 1000°C to complete the combustion reaction. Continuous-feed primary chamber provide more turbulence as compared to batch incinerator, in which off-gases may require an air pollution control (APC) system. The emission levels mandated by local environmental regulations & the waste composition will dictate the design selection of the APC. In general, the APC design includes stages to cool, neutralize and capture entrained particulate matter within the exhaust gas stream, before they can exit the stack. The ash produced by a continuous-feeding incinerator requires continuous ash discharge. Generally, this function is performed by a wet ash conveyor system that will operate automatically.



Source: Eco Waste Solutions, 14-5195 Harvester Road, Burlington, OntarioL7L 6E9, Canada.
1. Continuous Loading System; 2. Primary Combustion of Waste; 3. Combustion of Volatile Gases; 4. Waste Heat Boiler – Heat Recovery 5. Emission Controls – Acid Neutralization; 6. Emission Controls – Metals/Organics; 7. Emission Controls – Dust/Particulate; 8. Exit of Clean Gaseous Emissions; 9. Ash Removal - Conveyor; 10. Controlling and Monitoring of Process; 11. Emergency Bypass Stack.

Figure 2. Continuous type waste incinerators.

Other techniques for waste incineration are

1. Open burning
2. Single-chamber incinerators
3. Tepee burners
4. Open-pit incinerators

5. Multiple-chamber incinerators
6. Controlled air incinerators
7. Central-station disposal
8. Rotary kiln incinerators

1.1.3. Open Burning

It is the oldest technique for incineration of wastes. Mainly, it consists of placing or piling waste materials on the ground and burning them without the aid of specialty combustion equipment. This type of system is found in most parts of the world. It results in excessive smoking and high particulate emission, and may result in a fire hazard. Open burning has been utilized to dispose of high-energy explosives such as dynamite. For proper incineration, the waste is placed on a refractory pad which is in turn placed over gravel, in a cleared location, remote from populated areas (Figure 3).

Source: Christine Wiedinmeyer et al., 2014.

Figure 3. Open burning of waste.

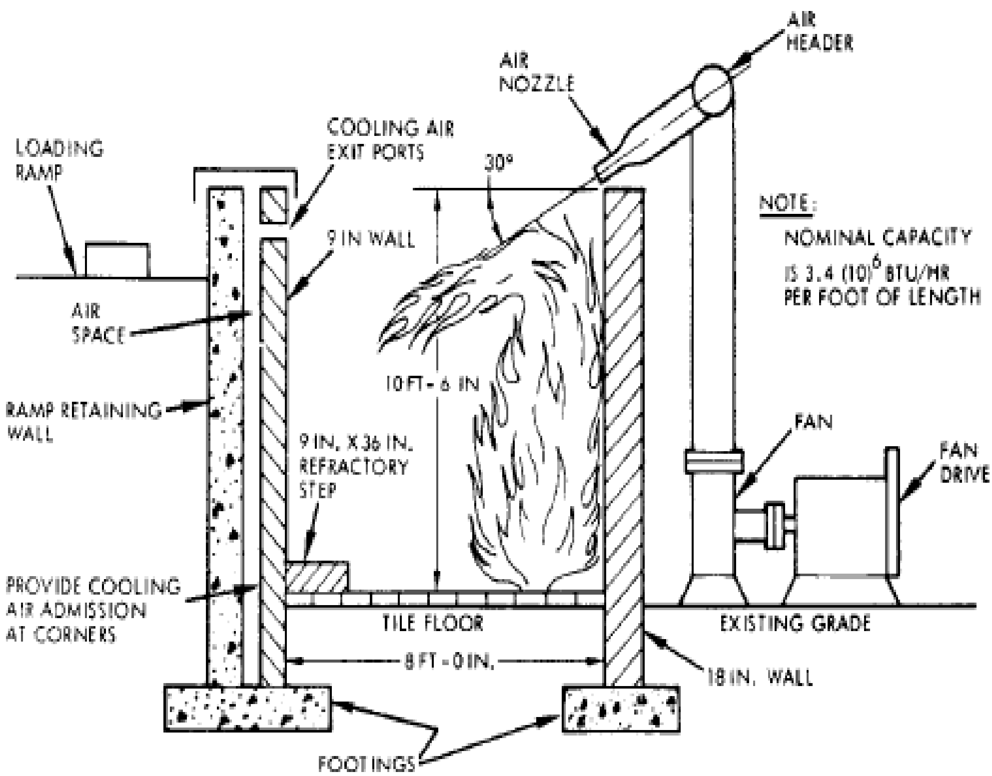
1.1.4. Single-Chamber Incinerators

In single-chamber incinerators solid waste is placed on the grate and fired. These incinerators have also been manufactured in top-loading (flue loading) configuration for apartment house waste disposal. It does not meet the air pollution emission standards. It is generally used for the destruction of cotton waste and other waste agricultural products.

1.1.5. Open-Pit Incinerators

It has been developed for controlled incineration of explosive wastes, which would create an explosion hazard or high heat release in a conventional, enclosed incinerator. They are constructed with an open top and a number of closely spaced nozzles blowing air from the open top down into the incinerator chamber. Air is blown at high velocity, creating a rolling action (i.e., a high degree of turbulence). Burning rates within the incinerator provide temperature in excess of 2000°F with low smoke and relatively low particulate emissions discharges. Incinerators of this type may be built either above or below ground. They are constructed with refractory walls and floor or as earthen trenches. The width of an open-pit incinerator is normally of the order of 2.4m, with a depth of approx. 3m. The length varies from 2.4 - 4.8 m. Air nozzle of 25- 30mm in diameter is located above one edge of the pit at the top of the incinerator. They fire down at an angle of 25° to 35° from the horizontal. The incinerator is normally charged from a top-loading ramp on the edge opposite the air nozzles. Some units have a mesh placed on their top to restrict larger particles of fly ash. Residue cleanout doors are often provided on above ground incinerators. Other than controlling combustion, there is no mechanism that is practically possible for control of exhaust emissions.

To assure complete burnout of products of combustion and decrease the airborne particulate loading in the exiting flue gas, multiple chamber incinerators have been developed. A primary chamber is used for combustion of solid waste. The secondary chamber provides the residence time, and supplementary fuel, for combustion of the unburned gaseous products and airborne combustible solids (soot) are discharged from the primary chamber (Figure 4).



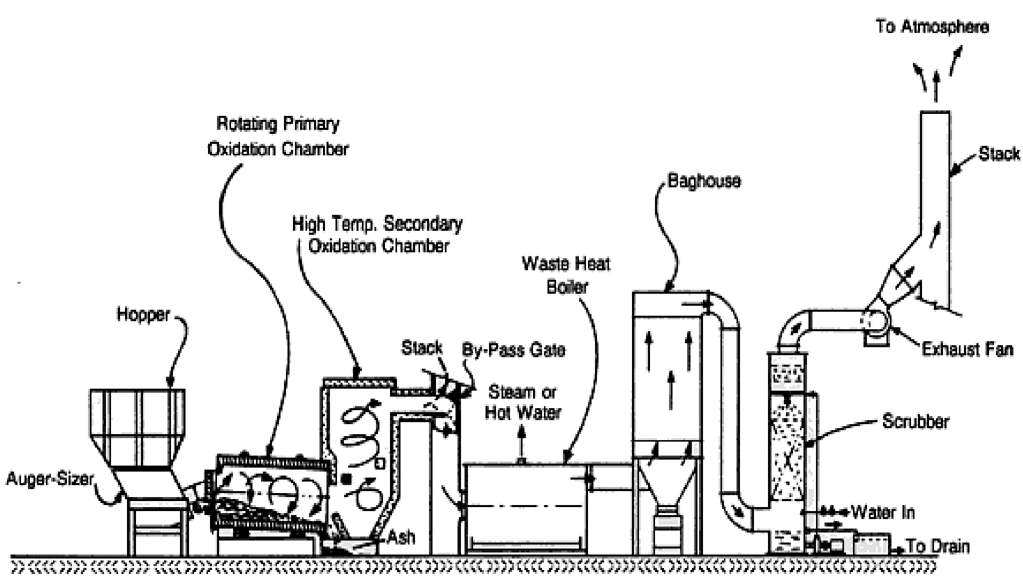
Source: Leonard C. Peskin (1966).

Figure 4. Open-pit incineration of waste.

1.1.6. Rotary Kiln

The rotary kiln is the primary combustion chamber of a rotary kiln incineration system. The basic components of a rotary kiln incinerator are the shell, the refractory lining, support tires and rollers, drive gear and internal heat exchangers. The kiln is a cylindrical vessel, inclined about 3-3.5% horizontally from axis, which is rotated slowly about its axis. The material to be processed is fed into the upper end of the cylinder. As the kiln rotates, material gradually moves down towards the lower end, and may undergo a certain amount of stirring and mixing and heated at more than 1000°C. It will fire the waste charged, but the volatile and organic compounds from the burning waste will exit in the gas stream and will not necessarily be burned in the kiln itself. A secondary combustion chamber is required for this system. Hot gases pass along the kiln, sometimes in the same direction as the process material (co-current), but usually in the opposite direction (counter-current). The hot gases may be generated in an external furnace, or may be generated by a flame inside the kiln.

Rotary kiln incinerator has 2 chambers: primary chamber and secondary chamber. The primary chamber in a rotary kiln incinerator consists of an inclined refractory lined cylindrical tube. The inner refractory lining serves as sacrificial layer to protect the kiln structure. This layer needs to be replaced from time to time. Movement of the cylinder on its axis facilitates movement of waste. In the primary chamber, there is conversion of solid fuel to gases, through volatilization, destructive distillation and partial combustion reactions. The secondary chamber is necessary to complete gas phase combustion reactions. The clinkers or diffused ash spill out at the end of the cylinder. A tall flue-gas stack, fan, or steam jet supplies the needed draft. Ash drops through the grate, however many particles are carried along with the hot gases. The particles and combustible gases may combust in secondary chamber. A conveyor is adaptable to transmit the slag and ash out of the furnace (Figure 5).



Source: Handbook for the Operation and Maintenance of Hospital Medical Waste: Incinerator.

Figure 5. Rotary kiln incineration of waste (with auger feed).

ADVANTAGES AND DISADVANTAGES OF INCINERATION TECHNOLOGY

Advantages:

1. Most suitable for high calorific value waste, pathological wastes.
2. Units with continuous feed and high through-put can be set up.
3. Thermal Energy recovery for direct heating or power generation.
4. Relatively noiseless, odorless and low land area requirement.
5. Can be located within city limits, reducing the cost of waste transportation under hygienic conditions.

Disadvantages:

1. Least suitable for aqueous or high moisture content, low calorific value and chlorinated waste.
2. Excessive moisture and inert content affects net energy recovery; auxiliary fuel support may be required to sustain combustion.
3. Concern for toxic metals that may concentrate in ash, emission of particulates, SOx, NOx, chlorinated compounds, ranging from HCl to Dioxins.
4. High capital and operation and maintenance costs.
5. Skilled personnel required for operation and maintenance.
6. Overall efficiency low for small power stations.

Indian Scenario for Incineration Technology

In India due to non-availability of effective regulations and control on rag-picking, waste burning, waste segregation at source and waste recycling activities could not be carried out. The left-over waste at the dumping yards generally contains a high percentage of inert (>40%) material, and of putrescible organic matter (30-60%). i.e., solid waste that contains organic matter capable of being decomposed by microorganisms.

It is a common practice of putting the road sweepings in the dust bins. Papers and plastics are mostly picked up and only such fraction which is in an unrecoverable form remains in the refuse. Paper normally constitutes 3-7% of refuse while the plastic, content is normally less than 1%. The calorific value on dry weight basis (High Calorific Value) varies between 800-1100 kCal/kg**.** Self-sustaining combustion cannot be obtained for such waste and auxiliary fuel will be required. Incineration, therefore, has not been preferred widely in India so far. The only incineration plant installed in the country at Timarpur, Delhi way back in the year 1990 has been lying inoperative due to mismatch between the available waste quality and plant design.

Studies on waste to energy in India show that Indian waste is unfit for the purpose of harnessing energy. However, Delhi government plans to install three waste-to-energy plants in the city. However with the fear of losing their means of living, rag pickers from across the country have opposed Delhi government’s plan. The main objection was “How can the proposed energy generation of 40 MW justify the loss of 350000 rag pickers livelihood?”

Myths and Facts About Incinerator

Myth 1– No incinerator manufactured in India meets current norms.

Fact – Incinerator designs in India are already in a fairly advanced stage. Many companies are in the process of exporting machines to Europe and North America.

Myth 2 – Incineration is an outdated western technology that is being dumped on gullible countries like India. Incineration is banned in most western countries.

Fact – Far from being banned, this is the status in 3 developed nations:

United States – 'Currently, over 90% of potentially infectious medical waste is incinerated'.

Germany – 'The arguments against waste incineration plants in particular are still found in many places in the world where such facilities are planned. Today, however, technologies are available which have made waste incineration a clean and environmentally sound form of waste management, so that such opposition is now unfounded'.

Australia – 'Incineration is the only permitted method of destruction of medical wastes in South Australia'.

Myth 3 –Incinerators produce dioxins.

Fact – Dioxins are generated in residential fireplaces, open burning, home grills, diesel engines, paper mills, pesticide and wood-preservative manufacturing units, chemical industries, etc. Dioxins are generally formed in the lower temperature range and only in the presence of halogens like chlorine. An incinerator testing programme in Canada showed that concentrations of dioxins and furans tend to be effectively destroyed when the temperature is raised to 1200°C.

Myth 4 – Banning incinerators will ensure a cleaner atmosphere.

Fact – Modern systems have excellent emission control facilities. To ensure a cleaner atmosphere, why not ban all automobiles and reduce lead, benzene and suspended particulate matter emissions? If we compare an incinerator's emission to the vehicles traversing on a busy road, we will find that CO emissions from the vehicles will be 47 times higher.

Myth 5 – Incineration has the worst environmental impact compared to other methods of managing waste.

Fact – All methods like recycling, composting, land filling and incineration have similar environmental impacts. Comparison of impacts is difficult because alternative systems generate different pollutants having various toxicities, effects, risks and modes, affect different populations and ecosystems. Analysis of health risks from dioxins and trace metals in composting and incineration processes indicate that since, human exposure to these substances is greater through food chain pathways than through inhalation pathways, the risks may actually be higher from composting than incineration.

2. GASIFICATION TECHNOLOGY

Combustion occurs in the presence of sufficient oxygen to completely oxidize the fuel, i.e., convert entire carbon present to carbon-di-oxide, all hydrogen to water, and the entire sulfur to sulfur dioxide. However, gasification is a process that occurs even when the oxygen is not sufficient. In gasification, the fuel undergoes partial combustion. In this condition, due to partial thermal decomposition of fuel, a mixture of gases such as CO_2, CO, H_2, N_2, CH_4 and traces of water vapor is produced. This mixture of gases is called producer gas. This process is called as gasification and the device in which the gasification is carried out is known as gasifier.

Gasification produce syngas or producer gas depending upon the oxidizing medium, which can be used as a feedstock for ethanol, methanol, naphtha, hydrogen, acetic acid, dimethyl ether, and ammonia. Syngas and producer gas can be co-fired with natural gas in conventional turbines and fuel cells or co-fired in coal-fired boilers to generate electricity. Gaseous fuels can be distributed by pipeline from a gasification plant for direct use in other locations. An important advantage of gasification compared to combustion is its potential to achieve higher efficiencies (more than75%) and lower emissions. The efficiency of a biomass-fired steam turbine system is between 20% and 25%. However, syngas-fueled engines and turbines can achieve system efficiencies in the range of 30% to 40%.

The thermo-chemical conversion of solid waste into a gaseous fuel (consisting of a mixture of CO, CO_2, N_2, CH_4 and H_2), which takes place under a sub-stoichiometric air supply condition is called solid waste gasification. The producer gas so produced has a low calorific value (1000-1200 kCal/Nm^3), but can be burnt with a high efficiency and a good degree of control without emitting smoke. Typical composition of producer gas is given in Table 2. Each kilogram of air-dry biomass (10% moisture content) yields about 2.5 -3.0 Nm^3 of producer gas. In energy terms, the conversion efficiency of the gasification process is in the range of 70%-80%. All the gasifiers have mainly four zones:

Drying (temperature up to 160 °C),
Pyrolysis (temperature between 200 – 800°C),
Oxidation (temperature between 850 – 1200°C)
Reduction (temperature between 900 – 400°C).

However, the position of these zones is not fixed; it varies depending upon the temperature of the reactor. A large number of designs for gasifier are available in national as well as international markets. Depending upon the characteristics of the solid waste and application of the producer gas, the design can be selected. In general, for the gasification of municipal solid waste, open core (throat less) downdraft gasifier (Figures 6 and 7) is used.

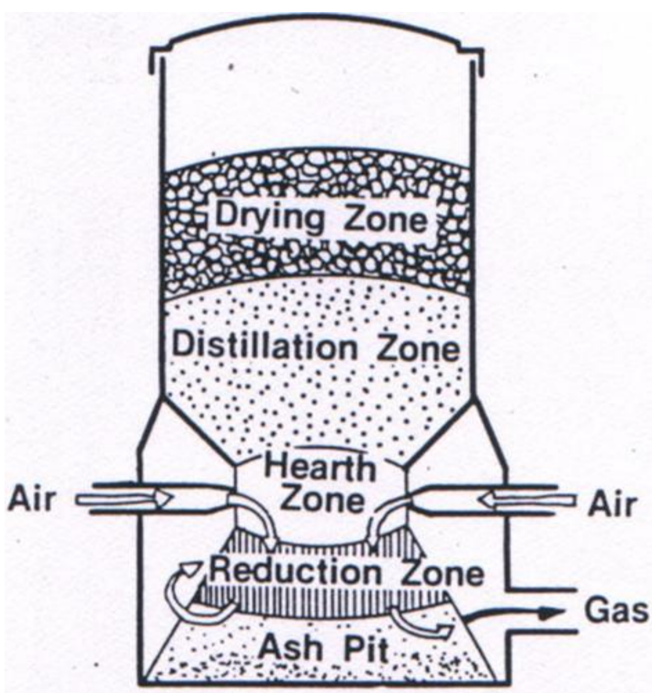
Table 1. Composition of producer gas

Sr. No	Component	Vol.%
1	Carbon-mono-oxide (CO)	18-21
2	Carbon-di-oxide (CO_2)	8-10
3	Hydrogen (H_2)	14-16
4	Methane (CH_4)	1-4
5	Nitrogen (N_2)	50-55
6	Water (H_2O) Vapour	4-5

Source: Reed & Das, 1988.

Source: Singh et al., 2006.

Figure 6. Open core downdraft gasifier.



Source: REED and Das, 1988.

Figure 7. Throat type downdraft gasifier.

APPLICATIONS OF PRODUCER GAS

Once producer gas is obtained from organic solid waste, it has number of applications, which can be broadly categorized in to three categories.

1) **Thermal applications**: cooking, water boiling, steam generation, drying etc.
2) **Motive power applications**: Using producer gas as a fuel in IC engines for applications such as water pumping.
3) **Electricity generation**: Using producer gas in dual-fuel mode in diesel engines or 100% producer gas in spark ignition engines.

2.1. Plasma Gasification

Plasma is the fourth state of matter and a very basic phenomenon of universe which is present in the sun, stars, lighting and all extraterrestrial entities having very high temperature of about 5000°C to 7000°C and high content of heat energy. By creating plasma artificially, we can use this heat energy to convert almost all types of solid waste into very useful products like synthetic gas, distilled ethanol and distilled hydrochloric energy that disintegrates the carbonic material to the basic element, i.e., which reacts with the ionized steam to form syngas. The two major global critical problems; solid waste management and power crisis in developing countries can be solved by the plasma gasification up to some extent. Though some techniques that are popularly used in the management of solid waste are:

- Land filling
- Incineration
- Recycling
- Biological reprocessing etc.

Land filling and incineration are the majorly used techniques around the globe but these conventional techniques have some major disadvantages:

Land filling: Kills surface vegetables, release of greenhouse gases like CO_2 and CH_4, odor problem.
Incineration: Emission of pollutants like dioxins.

2.1.1. What Is Plasma?

Plasma refers to every gas of which at least a percentage of its atoms or molecules are partially or totally ionized. In a plasma state of matter, the free electrons occur at reasonably high concentrations and the charges of electrons are balanced by positive ions. As a result, plasma is quasi-neutral. It is generated from electric discharges, e.g., from the passage of current (continuous, alternate or high frequency) through the gas and from the use of the dissipation of resistive energy in order to make the gas sufficiently hot. Plasma is characterized as the fourth state of matter and differs from the ideal gases, because it is characterized by 'collective phenomena' which originates from the wide range of Coulomb forces. As a result, the charged particles do not interact only with neighboring particles through collisions, but they also bear the influence of an average electromagnetic field, which is generated by the rest charges (Figure 8). In a large number of phenomena, collisions do not play an important role, as 'collective phenomena' take place much faster than the characteristic collision time. Plasma technology is very drastic due to the presence of highly reactive atomic and ionic species and the achievement of higher temperatures in comparison with other thermal methods. In fact, the extremely high temperatures (several thousand degrees on Celsius scale) occur only in the core of the plasma, while the temperature decreases substantially in the marginal zones. Generally plasma gasification is done by two ways, i.e., either electric arc or microwave radiation.

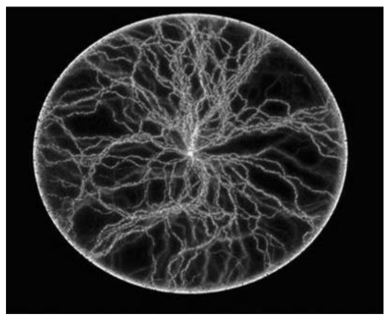
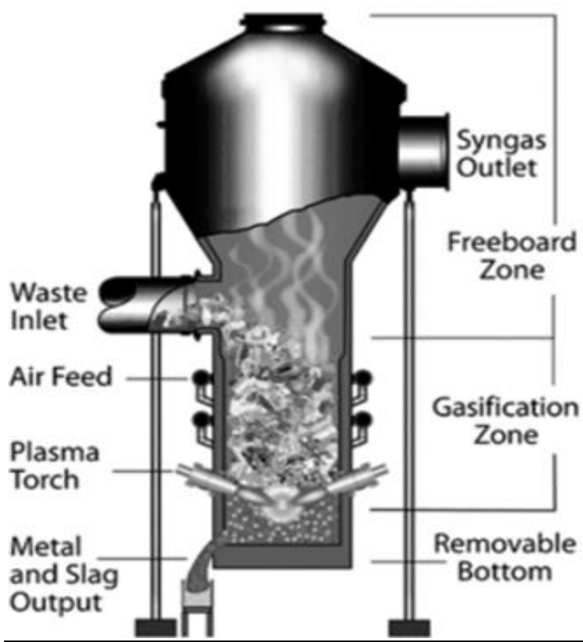


Figure 8. Plasma phenomena.



Source: Gp Capt (Retd) K.C. Bhasin; 2009.

Figure 9. Plasma arc gasification.

2.1.2. Plasma Arc Gasification

The conventional way to generate plasma is by electrical way. A high voltage source of about 650V electric current is passed between two electrodes. This rips electrons from the air and steam and creates plasma. A constant flow of electricity through the plasma maintains a field of extremely intense energy powerful enough to disintegrate the carbonic material into its component elements (Figure 9). The by product is a glass-like substance used as raw material for high-strength asphalt or household tiles and Syngas.

LIMITATIONS OF PLASMA ARC GASIFICATION

1. In plasma arc gasification, the plasma generation by arc itself consumes 80% of energy generated.
2. In arc the energy is focused to a single point whereas in the case of microwaves, a whole area is available for applying the heat. Plasma is generated at the very beginning when the matter enters the microwaves. Energy is applied directly to the matter to form a vortex, helping the heat reach a plasma state and subsequent reaction afterwards.
3. The plasma jet properties and quality is stable as compared to the arc plasma, as it has no electrode and therefore no electrode vapour contamination.
4. The nozzle electrode erosion is ignored as the nozzle stays relatively cold since the plasma is operated in the open air at the tip of the nozzle.

In terms of production of electricity, a conventional gasification plant is able to produce about 685 kilowatt hours (kWh) of net energy to the grid out of one ton of MSW, while a plasma arc gasification plant produces about 816 kWh. Microwave plasma gasification promises to produce about 2000 kWh per ton of MSW, which is more than 100% efficiency improvement. This is mainly due to the fact that the plasma-arc process consumes about 80% of the energy they generate while microwave gasification process only consumes 20% of the energy generated. However, microwave radiation gasification technology to generate plasma is still not fully developed and under research.

2.1.3. Plasma Generation Using Microwave Heating

Microwave is electromagnetic wave with wavelength ranging from 0.3 GHz to 300GHz, with energy 1.2μeV to 1.24 meV. When this microwave comes in contact with the inert gas (steam) then many molecules are electric dipoles, meaning that they have a partial positive charge at one end and a partial negative charge at the other, and therefore rotate as they try to align themselves with the alternating electric field of the microwaves. Rotating molecules hit other molecules and put them into motion, thus dispersing energy. This energy, when dispersed as molecular vibration (i.e., as both potential energy and kinetic energy of atoms), is converted into heat with temperature above 3000°C to 10,000°C.

MICROWAVE PLASMA GASIFICATION

The plasma generated by microwave is called 'Plasmatron' that is a plasma beam which is directed onto the carbonic material. Due to high temperature of about 3000°C to 10,000°C, carbonic material unleashes such large quantity of energy that a plasma field is generated. Due to this reaction, the incoming solid material and saturated steam go through a phase transformation that forces the carbon, oxygen and hydrogen molecules to break loose. Once these molecules leave the plasma field, they attach to each other forming a new molecular structure, called the 'Syngas' ($CO + H_2$).

The beauty of "Plasma Gasification" is plasma can disintegrate any type of material into the basic element due to high temperature field. The world's greatest problem of solid waste management can be solved by this process by using solid waste of almost any kind.

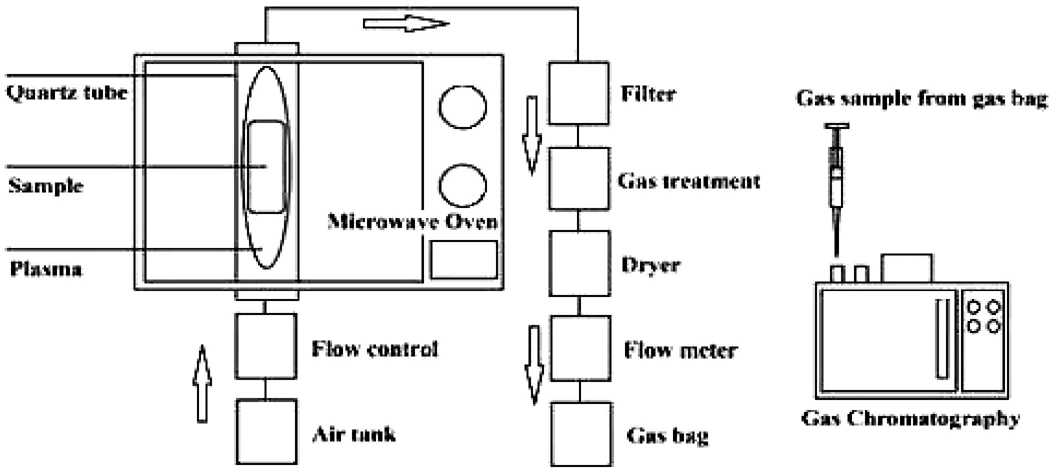
It may provide the solution to two very critical problems of power crisis and solid waste management by gasifying the solid waste into syngas ($CO + H_2$) and this 'syngas' can be used for power generation. The following solid waste can be used for this process:

- Tire waste
- Medical waste
- Furniture
- Industrial waste
- Municipal Solid waste
- Electronic waste
- Appliances waste
- Plastic and junk

WORKING OF MICROWAVE PLASMA GASIFIER FOR SOLID WASTE

All the solid waste shattered into small parts is put in milling roller and then through conveyor, these solid wastes is fed into the gasifier in primary zone having a temperature of about 1000°C to 1200°C where plasma already exists (Figure 10). In primary zone at the time of startup plasma is generated with the help of plasmatron gun in which inert gas (steam) is ionized by the microwave radiation. The core temperature of plasma is about 2760°C to 4427°C and the envelop temperature is about 1000°C to 1200°C which creates the primary zone.

Now, when solid waste comes in contact with plasma field then due to ionized inert gas molecule, collision with carbonic material molecules increases the temperature and due to heat, long chain of carbonic material ultimately converts into the basic element that is carbon, hydrogen and oxygen in the primary zone. When these basic elements go into the secondary zone where the plasma field does not exist and temperature range is from 750°C to 900°C, the basic element again reacts with each other and form syngas ($CO+H_2$) with the calorific value of 173.5kJ/mole. The syngas is collected in the upper part of gasifier with dome shape called cupola of gasifier where temperature is around 700°C to 750°C and pressure is about 2-3atm. Now this syngas after cleaning in the scrubber can be used in power plant using gas turbine or in petroleum plant for blending etc. The lower part of the gasifier is of conical shape which collect the slag that contain the inorganic solid mainly silica. About 0.5% slag comes out from gasifier at temperature of 900°C to 1000°C.



Source: Parin Khongkrapan et al., 2013.

Figure 10. Schematic of the microwave plasma setup.

Plasma Arc Gasification in India

In India, about 30 million tonnes of municipal solid waste and about 4400 million cubic metres of liquid waste are generated annually. The municipal solid waste generation ranges from 0.25 to 0.75 kg/day per capita with an average of 0.45 kg/day per capita. In addition, large quantities of solid and liquid wastes are generated by the industry. Most of the generated wastes find their way into land and water bodies without proper treatment, causing severe water pollution. They also emit greenhouse gases like methane and carbon dioxide, adding to air pollution. There exists a potential for generating an estimated 1700 MW of power from the urban and municipal wastes, and about 1000 MW from industrial wastes in the country. The two hazardous waste disposal plants with a capacity of 72tonnes/day and using WPC (Waste Pollution Control) gasification technology and plasma torches to produce electricity are under construction in Pune and Nagpur, by SMS Infrastructures, India. When operational, these are expected to produce 5 megawatts of electricity.

3. Pyrolysis

Pyrolysis is the thermal decomposition of solid waste occurring in the absence of oxygen. It is the fundamental chemical reaction that is the precursor of both the combustion and gasification processes and occurs naturally in the first two seconds. Principally, here the fuel is indirectly heated. Pyrolysis of solid waste generates three different energy products in different quantities: coke, oils and gases.

Teed et al. (1985) defines pyrolysis, gasification and combustion based on the amount of air supplied. According to them, when air supplied is less than 1 kg/kg of solid waste, process is under pyrolysis and when air supplied is in between 1 and 1.5 kg/kg of solid waste, thermal decomposition process is under gasification; however when air supply is sufficient, i.e., above 1.5 kg /kg of biomass process is under combustion. Moisture content and particle size of feed-stocks are two major parameters, which affects the pyrolysis process. The pyrolysis process is very much dependent on the moisture content of the feedstock, which should be around 10%. At higher moisture contents, high levels of watery bio-oils are produced and at lower levels there is a risk that the process only produces dust instead of bio-oil. On the other hand, particle size of feed-stocks is also a very important parameter; generally it is kept up to 2 mm. in view of the need for rapid heat transfer through the particle. Mainly here the fuel is indirectly heated. For thermal decomposition, containers having the powdery solid fuel are heated either electrically or thermally and latter heat is transferred from container wall to fuel particle, which is closer to wall and from there heat is transferred to next particle. Therefore larger particles (more than 2 mm) size may not able to transfer the heat properly to adjacent particles and ultimately reduce the overall efficiency of pyrolyser. Depending upon the heating rate and temperature of reactor it can be grouped in three categories. If heating rate is 4 -8°C/min and reactor temperature is less than 450°C, it is called low pyrolysis. Similarly if heating rate 5 -10°C/min and reactor temperature is in the range of 600-700°C, system behaves as fast pyrolyser. However if the heating rate is further increased i.e.10-15°C/s maintaining the reactor temperature in the range of 350 - 900°C, it is known as Flash Fast Pyrolysis.

Advantages and Disadvantages of Pyrolysis/Gasification Technology

Advantages:

1. Production of fuel gas/oil, which can be used for a variety of applications.
2. Compared to incineration, control of atmospheric pollution can be dealt with in a superior way, in techno-economic sense.

Disadvantages:

1. Net energy recovery may suffer in case of wastes with excessive moisture.
2. High viscosity of pyrolysis oil may be problematic for its transportation & burning.

4. Composting

Composting is a biological process in which micro-organisms, mainly fungi and bacteria, convert degradable organic waste into humus like substance. Output of the composting is known as compost, which is a mixture of decayed organic materials decomposed by microorganisms in a warm, moist, and suitable environment, releasing nutrients into readily available forms for plant use. Generally composting is done in two ways:

1. Anaerobic composting
2. Aerobic composting

Anaerobic composting is labor-free except pit digging. After about one year, the pit can be emptied and will yield fairly well-matured compost. Depending on the season and the actual rainfall during the composting time, the end product may still have smelly anaerobic lumps and not be pleasant to handle. It might not be the right treatment for young, tender and sensitive plants.

Aerobic composting, in general gives better matured compost, and takes shorter period, i.e., 2 - 4 months. But it requires more attention and labor. If properly built up, i.e., with enough roughage at base and proper aeration of the heap, composting process is assured. Here turning the heap at least once, not only for aeration, but for a breakdown of thicker lumps is necessary. There are some important parameters which effect compost quality such as:

- Nutrients and Substrate
- Chemical Elements
- Carbon-to-Nitrogen Ratio
- Particle Size
- Air/Oxygen
- Moisture Content (45 to 50%)
- pH Level *(*6.0 - 7.5)
- Temperature

Nutrients and Substrate: In composting, substrate and nutrient supply are synonymous because the substrate is the source of nutrients. Although the ideal waste would contain all necessary nutrients, in practice it may be necessary at times to add a chemical nutrient to remedy a nutrient deficiency.

Chemical Elements: The major nutrient elements are carbon (C), nitrogen (N), phosphorus (P), and potassium (K) and are collectively known as macronutrients. Apart from that, substrate also have cobalt (Co), manganese (Mn), magnesium (Mg), and copper (Cu) called as micronutrients. Carbon is oxidized (respired) to produce energy and metabolized to synthesize cellular constituents. Nitrogen is an important constituent of protoplasm, proteins, and amino acids.

Carbon-to-Nitrogen Ratio: The available carbon to nitrogen ratio (C/N) is the most important of the nutritional factors. The ideal C/N ratio is about 20/1 to 25/1. Higher C/N ratio can slow the compost process, however too low C/N (less than 15/1 to 20/1) leads to loss of nitrogen as ammonium N.

To maintain the proper available carbon to nitrogen ratio in the substrate, co-composting should be encouraged. The term co-composting means the composting of two or more raw materials together. In the case of organic part of MSW and sewage sludge, this kind of composting is advantageous because the two waste materials complement each other well. The sewage sludge is high in nitrogen content and moisture and the MSW is high in organic (carbon) content and has good bulking quality. Proper mixing of the same ensures and optimum C: N ratio to enhance the biodegradation process.

Particle Size: Theoretically, the smaller the particle size, the more rapid the rate of microbial attack. However, too small particle size creates difficulty to maintain an adequate porosity in a composting mass. The suitable particle size should be between 13 mm to 50 mm.

Air/Oxygen: Oxygen availability is a prime environmental factor in composting. Oxygen is a key element in the respiratory and metabolic activities of microbes.

Moisture: Permissible maximum moisture content in the substrate should be about 45-50%, above which oxygen availability becomes inadequate and anaerobic conditions ensures.

pH Level: The optimum pH range for most bacteria is between 6.0 - 7.5, whereas for fungi it is 5.5 - 8.0. Generally the pH level begins to drop during the initial stages of the compost process, as bacteria break down complex carbonaceous materials to organic acid intermediates. Organic acid helps the development of a microbial population and resulted in rise in pH level to as high as 8.0 to 9.0.

Source: The Art and Science of Composting, 2002.

Figure 11. Windrow composting of MSW.

Temperature: Experimental evidence shows that up to a certain point, chemical and enzymatic reactions are accelerated by each increment in temperature. For enzymes, the acceleration continues up to the point above which they are inactivated. Experience shows that the upper limit for most thermophiles involved in composting is between 55 - 60°C and, accordingly, the process is adversely affected if temperatures rise above this range.

Composting Systems: Composting systems broadly can be categorized in two groups, Windrow and In-vessel. Windrow composting is the production of compost by piling organic matter or biodegradable waste, such as animal manure and crop residues, in long rows (windrow) (Figure 11). This method is suited to producing large volumes of compost. The rows are generally turned to improve porosity and oxygen content, mix in or remove moisture, and re-distribute cooler and hotter portions of the pile. The temperatures of the windrows must be measured and logged constantly to determine the optimum time to turn the windrows for quicker compost production. In windrow composting, milling and stacking the raw waste accomplishes the initial aeration.

4.1. Windrow Composting

Aeration of Windrow Composting: Windrows can be aerated by turning, by forced aeration, or by a combination of the two. Turning is accomplished by tearing down and then reconstructing the windrow (Figure 12). Tearing down and reconstructing the windrow exposes the composting material to the ambient air and replenishes the interstitial oxygen supply. The resulting mixing renews microbial access to nutrients and disperses metabolic intermediates. The cooling effect of turning can be used for lowering a pile temperature that has reached inhibitory levels. Ideally, frequency of turning should be a function of rate of oxygen uptake by the active microbial population. In general turning every third day is sufficient to meet the oxygen uptake in actively composting MSW.

Forced Aeration (Static Pile): The aeration of compost by turning is a very effective method, however it is costly. A major factor in favor of forced aeration is the fact that it is less expensive than turning. The construction of a windrow for forced aeration begins with the installation of a loop of perforated pipe on the compost pad. A blower is used to supply the air to the composting materials. The blower provides direct control of the process and allows larger piles. No turning or agitation of the materials occurs once the pile is formed. When the pile has been formed properly and where the air supply is sufficient and the distribution uniform, the active composting period is completed in about three to five weeks.

Calculation of Total Area of Windrow Pad: It can be divided in to four groups:

1. Total volume of feedstock to be composted,
2. Area occupied solely by windrows,
3. Maneuvering area, and
4. Total pad area.

Total Volume of Feed Stock (m^3) to be composted can be calculated as:

{Retention time (days) x rate of feed stock delivery (kg/day)}/bulk density of substrate to be composted (kg/m^3)

Source: John Crockett, Research & development and MAF Composting System, Germany.

Figure 12. Aeration of Windrow Composting.

Area occupied by single windrows could be calculated in three steps.

Step 1. Determine the volume of each windrow.

Volume (m^3) = cross-sectional area (m^2) × length of windrow (m))

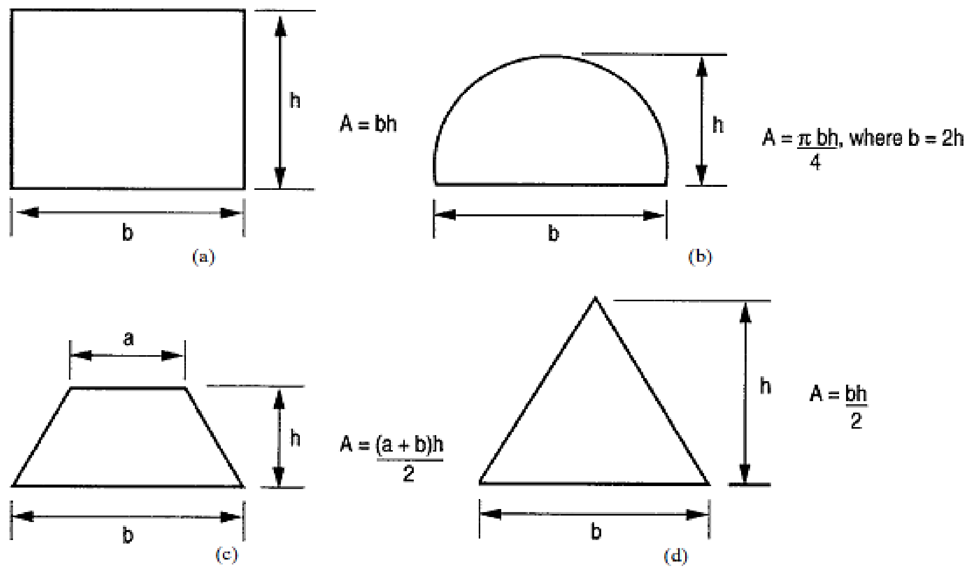
Cross-sectional area is a function of cross-sectional configuration which may have any shape e.g., rectangular/square (Figure a), semicircular (Figure b), Trapezoidal (Figure c), or triangular (Figure d), as mentioned below.

The cross-sectional area of a pile having a square or rectangular (Figure a) cross section (m^2) = base (m) × height (m).

The Cross-sectional area of the configuration having a semi-circular (fig b) Cross-sectional (m^2) = $\pi/4$ × b (m) × h (m).

The cross-sectional area of the configuration having a trapezoidal (Fig c) Cross-sectional area (m^2) = ½ (a + b) (m) × h (m).

The area of the configuration having a triangular (Fig d) Cross-sectional area (m^2) = ½ b (m) × h (m).



Step 2. Determine the number of windrows

Number of windrows may be calculated by dividing the total volume of feedstock (m^3) with individual volume of windrows (m^3)

Step 3. Determine the area solely occupied by windrows:

Total windrow area (m^2) = number of windrows × area per windrow (m^2)

Maneuvering Area: Maneuvering area is the space required to maneuver the turning and other equipment. Such spaces must be provided for each windrow (one on each side of a windrow).

Maneuvering area (m^2) = windrow/length (m) × width of space (m)

The width of a space depends upon the type of turning machine is used for turning the compost. For example bucket loader may require 1.22 m width, self-propelled turner may require 0.9 to 1.5 m width and tractor- assisted turner (two passes) may need 1.8 - 2.4 m width. In general the space between two individually aerated piles is kept about 20 ft (6.1m).

Total Area of Windrow Pad: The total Windrow pad area is the sum of the area required for the windrows plus that needed for maneuvering the material.

Solved Exercise: Suppose volume of material to be composted = 24 m^3/day and Composting period (detention time) = 50 days then

Total volume of material on pad = 50 days × 24 m^3/day = 1200 m^3

Dimensions of windrow: let length = 50 m, height = 3 m, & width = 4 m and windrow configuration is semicircular (Assumed)

Volume of windrow: V = ⅔ x (4 × 3) × 50 m^3 = 400 m^3

Number of windrows = total volume of material/volume of windrow 1200/400 = 3

Distance between windrows = 4 m

Space around perimeter of composting area = 3 m

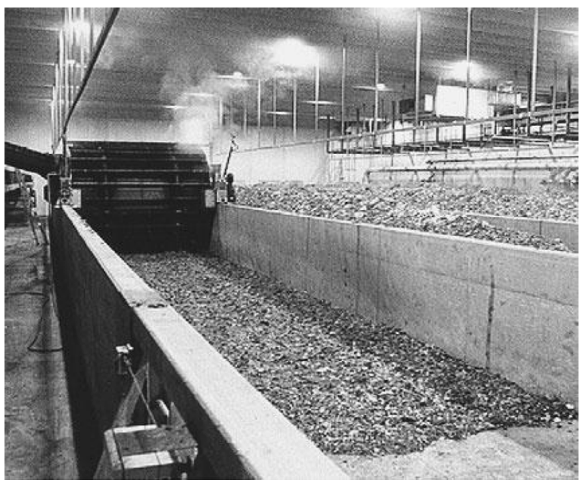
Length of composting area = windrow length and perimeter space = 50 m + (2 x3) = 56 m

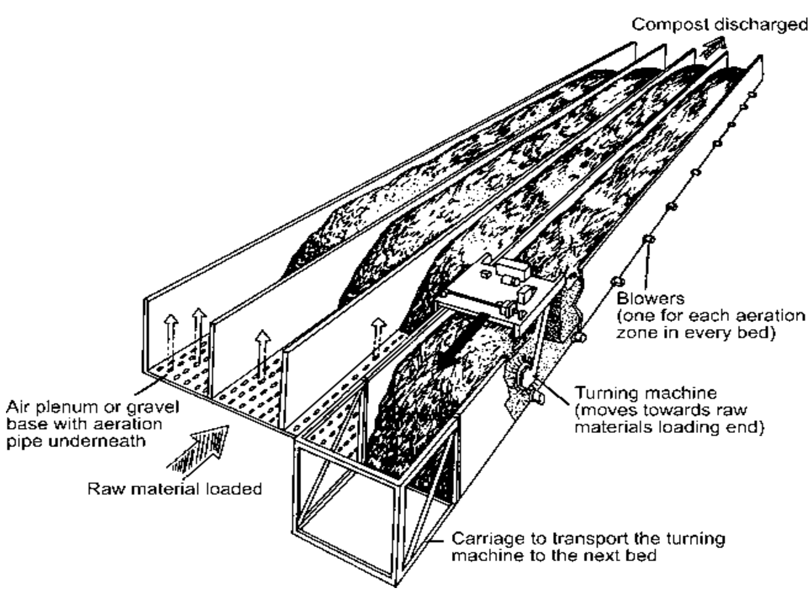
Width of composting area = width of windrows + distances between windrows + perimeter = (4 × 3) + (2 × 4) + (2 × 3) = 12 + 8 + 6 = 26 m

Area required = length × width = 56 × 26 = 1456 m^2

4.2. In-Vessel Composting System

The primary objective of the design of in-vessel composting system is to provide the best environmental conditions, particularly aeration, temperature, and moisture. Generally rectangular bed, forced aeration with combination of stirring, tumbling, or both is used in in-vessel systems.





Source: Spencer, 2007 and Rynk 1992.

Figure 13. In-Vessel Composting.

Rectangular agitated bed composting: The agitated bed system combines controlled aeration with periodic turning. The composting takes place between walls that form long, narrow channels referred to as beds (Figure 13). A rail or channel on top of each wall supports and guides a compost-turning machine. A loader places raw materials at the front end of the bed. As the turning machine moves forward on the rails, it mixes the compost and discharges the compost behind itself. With each turning, the machine moves the compost a fixed distance toward the end of the bed. Between turnings, aeration is also supplied by blowers to aerate and cool the composting material.

WINDROW V/S IN-VESSEL COMPOSTING SYSTEM

The capital cost of structures and equipment for the active phase of mixed MSW composting would be higher for the various in-vessel systems than for a conventional windrow system. In-vessel proponents claim that their systems have the potential for lowering operating costs by virtue of increased automation. In-vessel process configurations also require less land area per unit of throughput than is required for windrow composting. An important point is that regardless of the sophistication of the system, prudence demands that a generous buffer zone be provided.

CONSTRAINTS ON USE OF THE COMPOST

Constraints on the use of the compost with respect to the health and safety arise from the harmful substances that may be in the compost. Harmful substances may be heavy metals, toxic organic compounds (including PCBs), glass shards, and pathogenic organisms. The sources of harmful substances obviously are the wastes used as feedstock for the process. Concentrations of harmful substances usually are lower in the organic fraction of municipal solid wastes than in sewage sludge. These concentrations vary widely from operation to operation (e.g., cadmium ranges from 0 to 1100 μg/g dry sludge).

4.3. Vermi-Composting

Vermiculture is the science of cultivating earthworms which feed on waste material and soil and release digested food material back into the soil, thereby producing compost rich in nutrients, known as Vermi compost. Earthworms eat cow dung or farm yard manure along with other solid wastes and pass it through their body and in the process convert it into vermicompost (Figure 14). The municipal wastes; non-toxic solid and liquid waste of the industries and household’s garbage can also be converted into vermicompost in the same manner. Earthworms not only convert garbage into valuable manure but keep the environment healthy.

Method of preparation of Vermicompost: A thatched roof shed preferably open from all sides with unpaved (katcha) floor is erected in East-West direction length wise to protect the site from direct sunlight. A shed area of 12' x 12' is sufficient to accommodate three vermibeds of 10' x 3' each having 1' space in between for treatment of 9-12 quintals of waste in a cycle of 40-45 days. The length of shed can be increased/decreased depending upon the quantity of waste to be treated and availability of space. The height of thatched roof is kept at 8 feet from the centre and 6 feet from the sides. The base of the site is raised at least 6 inches above ground to protect it from flooding during the rains (Figure 14).

Source: FBR Foundation for biomedical Research, 2013 and School of Energy and Environmental Studies, DAVV, Indore.

Figure 14. Verms (earthworms) and Verms shed.

PROCEDURE FOR PREPARATION OF VERMI BEDS

The site marked for vermibeds on the raised ground is watered and a 4”-6” layer of any slowly biodegradable agricultural residue such as dried leaves/straw/sugarcane trash etc. is laid over it after soaking with water. This is followed by 1” layer of Vermicompost or farm yard manure. Earthworms are released on each vermin bed at the rates of 1.0 kg per bed for treatment of cow dung/agriculture waste and 1.5 kg per bed for treatment of household garbage. The frequency and limits of loading the waste can vary depending upon the convenience of the user. The loaded waste is finally covered with a jute mat to protect earthworms from birds and insects. Water is sprinkled on the vermin beds daily according to requirement and season to keep them moist. The waste is turned upside down fortnightly without disturbing the basal layer (vermin bed). The appearance of black granular crumbly powder on top of vermin beds indicates harvest stage of the compost. Watering is stopped for at least 5 days at this stage. The earthworms go down and the compost is collected from the top without disturbing the lower layers (vermin bed). The first lot of vermi-compost is ready for harvesting after 2-2 ½ months and the subsequent lots can be harvested after every 6 weeks of loading. The vermin bed is loaded for the next treatment cycle.

Advantages of Vermi-composting

1. Vermi-compost is an eco-friendly natural fertilizer prepared from biodegradable organic wastes and is free from chemical inputs.
2. It does not have any adverse effect on soil, plant and environment.
3. It improves soil aeration, texture and tilth thereby reducing soil compaction.
4. It improves water retention capacity of soil because of its high organic matter content.
5. It promotes better root growth and nutrient absorption.
6. It improves nutrient status of soil-both macro-nutrients and micro-nutrients.

Limitations

1. Vermi-compost pit should be protected from direct sun light.
2. To maintain moisture level, water should be sprayed on the pit as and when required.
3. The worms need to be protected from ants, rats and birds.

5. BIO-METHANATION

Bio-methanation is the anaerobic digestion of biodegradable organic waste in an enclosed space under controlled conditions of temperature, moisture, pH, etc. Depending on the waste characteristics, the waste mass undergoes decomposition anaerobically thereby generating biogas comprising mainly methane (55-65%), carbon dioxide (35-45%), traces of hydrogen sulfide (H_2S) and fractions of water vapors. A variety of waste sources like urban, agriculture, industrial sectors, vegetable markets, etc. generate huge quantities of solid waste containing a sizeable proportion of biodegradable organic matter with Municipal Solid Waste (MSW) having largest proportion. This material, if processed anaerobically, will not only generate significant quantity of biogas (about 250–350 m^3/ton of waste and manure) but will also reduce the load on land filling and will in turn prevent the degradation of environmental quality due to uncontrolled decomposition of organic matter in the landfills.

In India, most of the MSW is dumped and only a fraction (less than 10%) is intermittently processed in mechanical compost plants. Although the composting plants are found to be technically feasible, but due to competition from other manures and uncertainty over the utilization in the farms, very few plants are working at the designed capacity.

Bio- Methanation Process

Biogas can be produced by fermenting organic material in absence of air or oxygen with the help of bacteria to break down materials to intermediate stage such as alcohol and fatty acids and finally to methane, carbon dioxide and water. This process is called anaerobic fermentation. Anaerobic fermentation is a biological process, which takes place in absence of air or oxygen. A number of stages are involved, however broadly it can be divided in to three phases:

Phase 1: Hydrolysis

The waste materials of plant and animal origins consist mainly of carbohydrates, lipids, proteins and inorganic materials. Large molecular complex substances are solubilized into simpler ones with the help of extracellular enzyme released by the hydrolysis bacteria. Bacteria decompose the long chains of the complex carbohydrates, proteins and lipids into shorter parts. This stage is also known as polymer breakdown stage. For example, the cellulose consisting of polymerized glucose is broken down to dimeric, and then to monomeric sugar molecules (glucose) by cellulolytic bacteria.

Phase 2: Acidification

The sugar molecules produced in phase 1 is fermented under anaerobic condition into various acids with the help of enzymes produced by the acid forming bacteria. These bacteria are anaerobic and can grow under acid conditions. To produce acetic acid, they need oxygen and carbon. For this, they use the oxygen dissolved in the solution or bounded-oxygen. Thereby, the acid-producing bacteria create an anaerobic condition which is essential for the methane producing microorganisms. At this stage, the acid-forming bacteria break down molecules of six atoms of carbon (glucose) into molecules of lesser atoms of carbon (acids) which are in a more reduced state than glucose. The principal acids produced in this process are acetic acid, propionic acid, butyric acid and ethanol.

Phase 3: Methanization

The acids produced in phase 2 are further processed by methanogenic bacteria in to methane. For example, they utilize hydrogen, carbon dioxide and acetic acid to form methane and carbon dioxide. Under natural conditions, methane producing microorganisms occur to the extent that anaerobic conditions are provided, e.g., under water. The reactions that take place in the process of methane production is called methanization and is expressed by the following equations:

$$\underset{\text{Acetic acid}}{CH_3COOH} \rightarrow \underset{\text{Methane}}{CH_4} + \underset{\text{Carbon dioxide}}{CO_2}$$

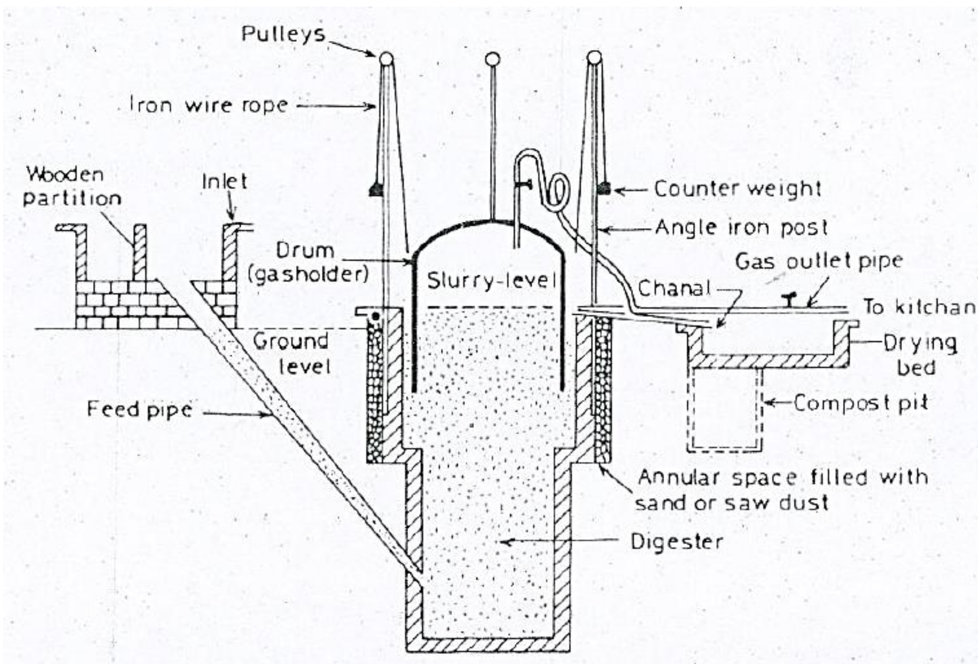
$$\underset{\text{Ethanol}}{2CH_3CH_2OH} + \underset{\text{Carbon dioxide}}{CO_2} \rightarrow \underset{\text{Methane}}{CH_4} + \underset{\text{Acetic acid}}{2CH_3COOH}$$

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Hydrogen}}{4H_2} \rightarrow \underset{\text{Methane}}{CH_4} + \underset{\text{Water}}{2H_2O}$$

Source: School of Energy and Environmental Studies, DAVV, Indore.

Figure 15. Floating dome Bio- Methanization reactor.

These bacteria are sensitive to change in their environment. Thus for better yield, mesophillic temperature range/thermophillic temperature range and pH of fatty acid may be maintained in between 6.8 to 7.4. Increasing acidity can be corrected by adding burnt lime until slurry becomes neutral. Biogas obtained from anaerobic fermentation/digestion is about 20% lighter than air and has an ignition temperature in the range of 65- 75^{0}C. It is an odorless and colorless gas that burns with clear blue flame similar to that of LPG. Although numbers of designs of Bio- Methanization reactors are available, however mostly floating dome (Figure 15) and fixed dome bio- methanization reactors (Figure 16) are used.



Source: K M Mital, 1996.

Figure 16. Fixed dome Bio- Methanization reactor.

APPLICATIONS FOR BIOGAS

Biogas obtained from Bio- Methanization reactor can be used for number of applications such as:

Cooking: For cooking application, in general 0.3 m^3 gas is needed /person/day considering the efficiency of biogas chulha is about 55-60%.

Lighting: With the use of biogas lamp, biogas could be used for lighting. Generally one biogas lamp supplies light equivalent to 40 W bulb. For lighting of one biogas lamp for one hour generally 0.15 m^3 biogas is needed, i.e., from 1 m^3 biogas we can get about 7 hours of light.

Welding Application: Generally oxyacetylene gas is used for welding, which gives about 3250°C temperature. Instead oxy-methane, which gives about 3000°C temperature can be used, however due to low temperature, it is more suited for brass welding instead of arc welding.

Refrigeration (Absorption Type): In general for 1 m^3 (1000 L) refrigeration, 1 m^3 biogas is needed e.g., for 165 L refrigerator, 1x 0.165x 24 =3.96 cum /day biogas is needed. However the flame of biogas must be controlled. At present no company except Benson & Telku is making burners, which could be used for refrigeration.

Incubator: Incubator, which is generally operated with kerosene, could be operated from biogas. For this purpose, like refrigeration Benson &Telku burner may be used. In general for 1 m^3 (1000 L) incubator, 0.7 m^3 biogas/h is needed e.g., for 144 L (60x60x40 cm) incubator, 1x 0.144x 24 =2.42 cum /day biogas is needed.

Electricity Generation: Up to 75-80% diesel can be replaced by biogas in CI engine at dual fuel mode; however spark engine can be operated on 100% biogas. To run 1 hp engine, generally 0.5 m^3 biogas is needed. Biogas is introduced in to the inlet manifold of the engine through air cleaner. A mixing chamber may be provided for uniform mixing of biogas and air before introducing into the inlet manifold. On dual fuel engine, the fuel is mixed with air towards the end of compression stroke of the engine and being sprayed in to the combustion chamber with high pressure (about 200 bar). The fuel is immediately ignited when it comes in contact with the hot compressed air.

Advantages and Disadvantages of Anaerobic Digestion

Advantages:

1. Energy recovery with production of high grade soil conditioner.
2. No power requirement unlike aerobic composting, where sieving and turning of waste. pile for supply of oxygen is necessary.
3. Enclosed system enables all the gas produced to be collected for use. Controls Green House Gases emissions.
4. Free from bad odor, rodent and fly menace, visible pollution and social resistance.
5. Modular construction of plant and closed treatment needs less land area.
6. Net positive environmental gains and can be done at small scale.

Disadvantages

1. Heat released is less resulting in lower and less effective destruction of pathogenic organisms than in aerobic composting. However, now thermophilic temperature systems are also available to take care of this.
2. Unsuitable for wastes containing less organic matter.
3. Requires waste segregation for improving digestion efficiency.

6. RECYCLING

Used materials are collected and reused as raw materials for new products. The process of recycling includes collecting recyclables, separating them by type, processing them into new forms that are sold to manufacturers, and, finally purchasing and using goods made with reprocessed material.

Sustainable Recycling

A sustainable recycling system requires a balance of inflows and outflows (Figure 17). In other words, the energy and resources invested in the recovery of materials should be equal to that invested in the delivery of goods to consumers.

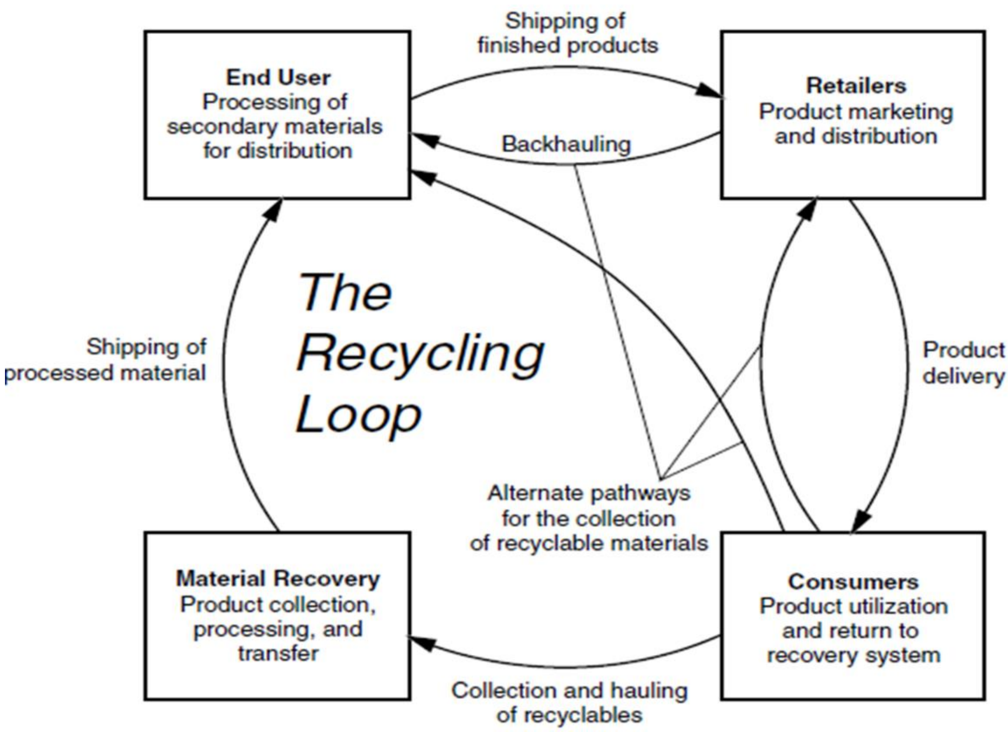


Figure 17: Sustainable recycling of solid waste.

Benefits of Recycling

1. Recycling reduces the need for land filling and incineration.
2. Recycling prevents pollution caused by the manufacturing of products from virgin materials.
3. Recycling saves energy.
4. Recycling decreases emissions of greenhouse gases that contribute to global climate change.
5. Recycling conserves natural resources such as timber, water, and minerals.
6. Recycling helps sustain the environment for future generations.

Some Facts about Recycling

1. 1 recycled tin can save enough energy to power a television for 3 hours.
2. 1 recycled glass bottle would save enough energy to power a computer for 25 minutes.
3. 1 recycled plastic bottle would save enough energy to power a 60- watt light bulb for 3 hours.
4. 70% less energy is required to recycle paper as compared to making it from raw materials.
5. Recycling plastic saves twice as much energy as burning it in an incinerator.
6. Each ton (2000 pounds) of recycled paper can save 17 trees, 380 gallons of oil, three cubic yards of landfill space, 4000 kilowatts of energy, and 7000 gallons of water.
7. This represents 64% energy savings, 58% water savings, and 60 pounds less air pollution.

Some Items That Can Be Recycled or Reused

Items	Their waste	Remarks
Paper	Old copies, Old books, Paper bags, Newspapers, Old greeting cards, Cardboard box	As per review, an estimated 1 ton of recycled paper saves approx. 17 trees, 2.5 barrels of oil, 4100 kWh of electricity, 4 m^3 of landfill & 31,780 L of water. 550 mills in India use waste paper.
Plastic	Containers, Bottles, Bags, Sheets	More than 50% of the plastic waste generated in the country is recycled and used in the manufacture of various plastic products such as plastic waste for construction of roads, street lighting with plastic waste, power generation from plastic waste, plastic to floor tiles etc.
Glass and ceramics	Bottles, Plates, Cup, Bowls	Every 1,000 kg of waste glass recycled into new items saves 315 kg of CO_2 from being released into the atmosphere during the creation of new glass.
Miscellaneous	Old cans, Utensils, Clothes, Furniture	Dharam Pal Woollen Industries, the company owned by Jindals, makes 10,000 kg of yarn a day from 20 tonnes of used clothes.

Exercise: If the recycling rate of aluminum can is 63%, calculate the energy required to produce the aluminum can of 355 ml capacity having weight about 16g. How much energy is saved, if a can is recycled instead of throwing away? Also estimate the amount of gasoline being wasted when one can is thrown away.

Solution: Since only 63% can is recycled, therefore 37% can need to be made from bauxite.

Thus energy needed for the 37% can made from bauxite =
0.016 kg/can x 0.37 x 17411 kcal/kg = 103.07 kcal/can

Energy needed for rest of the material, i.e., 63% from recycling of the aluminum can = 0.016 kg/can x 0.63 x 1072 kcal/kg =10.81 kcal/can.

Thus total energy needed for production of one can if 63% recycled aluminum is used= 113.88 kcal/can. Energy needed if can is made from bauxite= 0.016 kg/can x 17411 kcal/kg = 278.576 kcal/can. Energy needed if can is made from recycled aluminum = 0.016 kg/can x 1072 kcal/can =17.153 kcal/can.

% saving of energy= {278.567- 17.153}/278.567 = 93.84%

The equivalent amount of gasoline thrown away when a can is not recycled= {278.567-17.153} = 261.423 kCal saved. (Energy content of gasoline =10000 kCal/L, Gasoline equivalent =261.423/10000 =0.2614 L or 261.4 ml)

ENVIRONMENTAL BENEFITS FOR RECYCLING OF MSW

1. Recycling reduces greenhouse gas emissions.
2. Connecticut recycling efforts reduced greenhouse gas emissions by 3,40,000 metric tons of carbon equivalent per year, equal to approximately 19.1% of all industrial carbon dioxide emissions from fossil fuel combustion in the state and 3.0% of greenhouse gas emissions.
3. By reducing the amount of energy used by industry, recycling also reduces greenhouse gas emissions and helps stem the dangers of global climate change.
4. This reduction is because much of the energy used in industrial processes and in transportation involves burning fossil fuels like gasoline, diesel and coal, which is the most important sources of carbon and other greenhouse gas emissions into the environment.

7. LANDFILLS

Landfills are the most popular disposal option for municipal solid waste (MSW). It is not only the least cost effective option; it is also a solid waste management necessity because not a single combination of reduction, recycling, composting or incineration can currently manage the entire solid waste stream. An alternative method of land filling that is being tried in several locations throughout the world involves shredding of the solid wastes before placement in a landfill. Another approach is to bale the MSW for placement in the landfill. This method has the advantage of easier handling and eliminates the need for the compaction equipment. Balers increase landfill space by up to 45% and consequently extend the life span of landfill. In general two sizes of baler, higher capacity (55/60 tons/hour) and medium capacity (35/40 tons/hour) are available in the markets. Optional wrapping of bales significantly reduces to minimum classic problems, i.e., methane gas, leachate, wind and odor. Bale also brings down operation & maintenance costs: no landfill compactors, lower diesel costs and less soil cover.

Landfills could be classified in to three categories:

1. **Secure landfills** are designed to handle hazardous wastes.
2. **Monomials landfills** are designed to handle particular type of waste such as incinerator ash or sewage sludge that are relatively uniform in characteristics and require special handling.
3. **Sanitary landfills** refer to an engineered facility for the disposal of MSW, design and operated to minimize impact on public health and environment.

CLASSIFICATION OF LANDFILLS BASED UPON SIZE

There is no standard method for classifying landfills by their capacity. However the following nomenclature is often observed in literature:

Small size landfill : less than 5 hectare area
Medium size landfill : 5 to 20 hectare area
Large size landfill: greater than 20 hectare area.

Landfill depths are reported to vary from less than 5 m to well above 30 m.

TERMS RELATED TO LAND FILLING

Landfill: is the term used to describe the physical facilities used for the disposal of solid wastes and solid waste residuals in the surface soils of the earth.

Sanitary landfill: refers to an engineered facility for the disposal of MSW design and operated to minimize public health and environmental impacts.

Landfill for individual waste constituents such as combustion ash, asbestos, and other similar wastes are known as mono-fills.

The final landfill cover layer is applied over the entire landfill surface after all land filling operations are complete.

Landfill covers: consist of successive layers of compacted clay and/or geo synthetic material designed to prevent the migration of landfill gas and to limit the entry of surface water into the landfill.

Leachate: The liquid that forms at the bottom of the landfill is known as leachate.

Landfill gas: is the term applied to the moisture of gases found within a landfill.

Environmental monitoring involves the activities associated with collection and analysis of water and air samples used to monitor the movement of landfill gases and the leachate at the landfill site.

Landfill closure: is the term used to describe the steps that must be taken to close and secure a landfill site once the filling operation has been completed.

Post closure care refers to the activities associated with the long-term maintenance of the completed landfill (typically 30 to 50 years).

Remediation refers to those actions necessary to stop and clean up unplanned contaminant releases to the environment.

Cell: The term cell is used to describe the volume of material placed in a landfill during one operating period, usually one day. A cell includes the solid waste deposited and the daily cover material surrounding it.

Daily cover: usually consists of 6 to 12 inches of native soil or alternative materials such as compost, foundry sand, or auto shredder fluff that are applied to the working faces of the landfill at the end of each operating period. It is used to prevent rats, flies, and other disease vectors from entering or exiting the landfill. It also helps to control the blowing of waste materials, to reduce odors, and to control the entry of water into the landfill during operation.

Lift: A lift is a complete layer of cells over the active area of the landfill (see Figure b). Usually landfills comprise a series of lifts. A bench (or terrace) is typically used where the height of the landfill will exceed 50 to 75 ft.

Landfill liners: are materials (both natural and man-made) that are used to line the bottom area and below-grade sides of a landfill. Liners usually consist of successive layers of compacted clay and/or geo synthetic material designed to prevent migration of landfill leachate and landfill gas.

ADVANTAGE AND DISADVANTAGES OF LANDFILL OF MSW

Advantage

1. Landfill gas recovery is economical.
2. The gas produced can be utilized for power generation or as domestic fuel for direct thermal applications.
3. Highly skilled personnel not necessary.
4. Natural resources are returned to soil and recycled.
5. Can convert low lying marshy land to useful areas.

Disadvantages

1. Greatly polluted surface run-off during rainfall.
2. Soil/groundwater aquifers may get contaminated by polluted leachate in the absence of proper leachate treatment system.
3. Inefficient gas recovery process yielding 30--40% off the total gas generation.
4. Balance gas escapes to the atmosphere (significant source of two major Green House Gases - carbon dioxide & methane).
5. Large land area requirement.
6. Significant transportation costs to far away landfill sites may upset viability.
7. The cost of pre-treatment of gas to upgrade to pipe line quality and leachate treatment may be significantly high.

8. Spontaneous ignition/explosions due to possible buildup of methane concentrations in atmosphere.

LAND FILLING METHODS

The principal methods used for the land filling of MSW may be classified as:

1. Excavates cell/Trench Method (Below Ground Landfill)
2. Area Method (Above Ground Landfill)
3. Canyon Method

Mainly, land filling is categorized in to two categories, i.e., Trench method and Area method. Other approaches are only modifications of above two methods. In both the methods, refuse is dumped into a trench or in small rows (area method), compacted, and covered each day. The method selected depends on the physical conditions involved and the amount/types of solid waste to be handled.

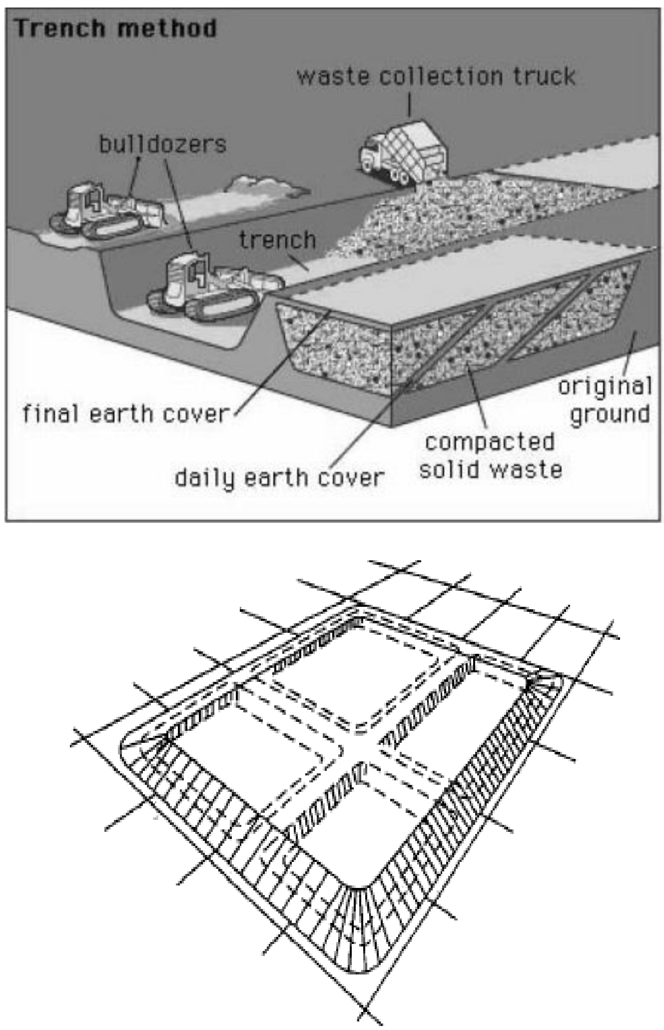
7.1. Trench Method

The cell/trench method of land filling is ideally suited to areas where an adequate depth of cover material is available at the site (more than 6 feet deep) and where the water table is not near the surface. It is best employed on flat or gently rolling land. Typically, solid wastes are placed in cells or trenches excavated in the soil (Figure 18). The soil excavated from the site is used for daily and final cover. Typically, solid wastes are placed in cells or trenches excavated in the soil. The soil excavated from the site is used for daily and final cover. The excavated cells or trenches are lined with synthetic membrane liners, low permeability clay, or a combination of the both depending upon the waste characteristics to limit the movement of both landfill gases and leachate. Excavated cells are typically square, up to 305 m in width and length, with side slopes of 2:1 to 3:1. Trenches vary from 61 to 305 m in length, 1 to 3m in depth, and 4.5 to 15 m in width. If land fill is to be made 1.8 m deep for 4000 personnel, about 1.25 hectares per year land is needed. At the end of each day when a section of trench has been filled and compacted with the bulldozer, the top, side, and end of the section is covered with earth. At least once each week the compacted refuse must be thoroughly sealed with the final compacted cover. This is done by covering the working face of the trench with at least 30 cm of well compacted earth. The necessity for complete sealing and compacting cannot be over-emphasized. Sealing and compacting reduces future settlement, prevents spread of fires, eliminates odors, and precludes insect and rodent problems. The excavated trenches are lined with low-permeability liners to limit the movement of both landfill gases and leachate.

ADVANTAGES AND DISADVANTAGES OF TRENCH METHOD OF LAND FILL

Advantages:

1. Not usually necessary to import cover material.
2. Can be operated with a minimum working face exposed.
3. Can be designed for optimum drainage during filling operations.
4. May provide better litter control.
5. Lower area/volume ratio (smaller amount of landfill surface area used per volume of waste deposited) may result in lower leachate production potential.



Source: Waste management alternatives.

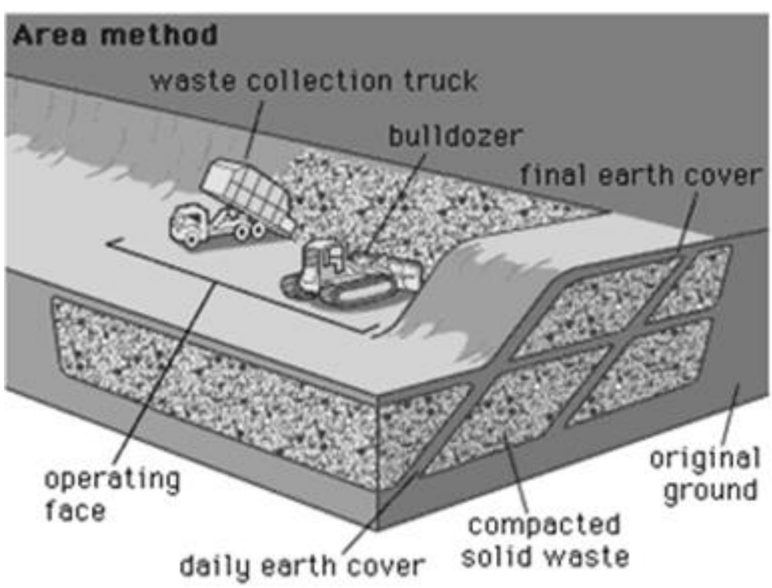
Figure 18. Cell/trench method of land filling.

Disadvantages:

1. Not suitable in geological areas with high excavation costs or shallow ground water.
2. Leachate collection may be more difficult/expensive.
3. Loss of landfill volume due to the "between trench" areas.
4. Trench depths and side slopes depend on soil types and stability.
5. Trench size may be insufficient to handle unexpected high traffic volumes of MSW.

7.2. Area Method

The area method is used when the terrain is unsuitable for the excavation of trenches to place the solid wastes and in high groundwater conditions. It can be followed on most topography and is often used if large quantities of solid waste must be disposed. Site preparation includes the installation of a liner and leachate management system. The wastes are unloaded and spread in long, narrow strips on the surface of the land in a series of layers that vary in depth from 40–75 cm. Each layer is compacted as the filling progresses during the course of the day until the thickness of the compacted wastes reaches a height varying from 2–3 m. At the end of each day's operation, a 30 cm layer of cover material is placed over the completed fill (Figure 19). The cover material must be hauled in by truck or earthmoving equipment from adjacent land or from borrow-pit areas. The filling operation usually is started by building an earthen levee against which wastes are placed in thin layers and compacted. The length of the unloading area varies with the site conditions and the size of the operation. The width over which the wastes are compacted varies from 2.5–6 m, depending on the terrain.



Source: Waste management alternatives.

Figure 19. Area method of land filling.

ADVANTAGES AND DISADVANTAGES OF TRENCH METHOD OF LAND FILL

Advantages:

1. Does not require excavation of trenches.
2. Useful in areas where the terrain may be unsuitable for trench operations.
3. Can accommodate high traffic volumes since the working face is not limited by the size of an excavation.

Disadvantages:

1. Cover material may have to be imported.
2. Potential exists for greater litter problems.
3. Larger overall area/volume ratio (greater amount of landfill surface area used per volume. of waste deposited) may result in higher costs.
4. Topographic control not as obvious as for trench operation.

7.3. Canyon/Depression Method of Land Filling

At locations where natural or artificial depressions exist, it is often possible to use them effectively for land filling operations. The technique to place and compact solid waste in canyon/depression landfills vary with the geometry of the sites, the characteristics of the available cover material. The hydrology and geology of the site, the type of leachate and gas control facilities to be used. Canyons, ravines, dry borrow pits, and quarries have been used for landfills. Pit and quarry landfill sites are always lower than the surrounding terrain, so control of surface drainage is often the critical factor in the development of such sites. Also, borrow pits and quarries usually do not have adequate soil or geological properties for land filling because they display high permeability and fracturing. As with gully sites, pit and quarry sites are filled in multiple lifts and the method of operation is essentially the same. A key to the successful use of pits or quarries is the availability of adequate cover material to cover the individual lifts as they are completed and to provide a final cover over the entire landfill when the final height is reached. Because of settlement, it is usually desirable to fill pit and quarry sites to a level slightly above that of the surrounding terrain. The depression method is also not readily amenable to liners and leachate collection system.

7.4. Modified Methods of Land Filling

Several modifications of basic landfill techniques are being used to extend site life, decrease the need for cover material, and save costs. The high-rise method involves stacking and compacting layers of waste on the ground surface, then covering each layer. Layers are placed on top of the others in form of a pyramid. However, as the layers move upward, the slopes reduce the size of the top area. The layers above ground minimize subsurface pollution and makes maximum use of limited land area. This method is popular in coastal areas or in the areas where the water table is high. You may need to haul cover material from other locations. The no-cover method involves spreading and compacting waste without covering it at the end of the day. This method, however, requires certain standards regarding control of insects, rats, odors, and other nuisances. Although it can extend the life of a landfill by 10 to 20% and cut operating and equipment costs, the no-cover technique has not been accepted in most locations.

7.5. Special Use Areas

The design of a landfill should also include provisions for special circumstances. For instance:

(i) An area near the landfill entrance where collection trucks can deposit their loads when wet weather prevents them from reaching the working face.
(ii) An area for demolition debris that normally does not have to be covered every day the way routine wastes do.
(iii) Special area or areas where toxic waste cleared for landfill disposal can be deposited.
(iv) Areas for disposal of bulky wastes such as tree stumps.
(v) Storage area for appliances and junk cars, if they are received in sufficient quantity to make this provision economical and are permitted for storage.
(vi) Areas for yard waste, including grass clippings, brush, mulch, and small branches when site is permitted for this material.
(vii) Citizen bin for safety of small private vehicles.
(viii) An area for a tub grinder to process landscape and wood waste.

LAND REQUIREMENTS FOR SWM TECHNOLOGY

The area of land required for setting up any waste processing/treatment facility generally depends upon the following factors:

Total waste processing/treatment capacity, which will govern the overall plant design/size of various sub-systems. Waste quality/characteristics, which will determine the need for preprocessing, if required, to match with the plant design. Waste treatment technology selected, which will determine the waste fraction destroyed/converted to energy. Quantity and quality of reject waste, liquid effluents and air emissions, which will determine the need for disposal/post treatment requirements to meet EPC norms. As such, the actual land area requirement can be worked out only in the Detailed Project Report (DPR) for each specific project.

However, for initial planning, the following figures may be considered for 300 TPD (input capacity) Waste-to-Energy facilities:

1. Incineration/Gasification/Pyrolysis plants : 0.8 hectare
2. Anaerobic Digestion Plants: 2 hectares (Based upon typical installations)

3. Sanitary Landfills (including Gas-to-Energy recovery): 36 hectares (For areas away from coast. It may be more in coastal areas). This is estimated on the basis of a filling depth of 7m and Landfill life of 15 years.

INTEGRATED WASTE MANAGEMENT

Integrated waste Management is a system of waste disposal that includes separating materials according to type, and finding the best use for discarded products, which may or may not include depositing them in a landfill. An integrated waste management program will not only handle household waste, but many other type of wastes as well. Special routes may specifically pick up industrial waste, which may have different requirements as far as treatment and disposal is concerned. Medical waste, also known as bio-hazardous material, will also be picked up in a special way. This helps to protect workers, as well as to reduce pollution and meet certain environmental standards outlined by the Environmental Protection Agency (EPA). The major ISWM activities are waste prevention, recycling, composting, combustion and disposal in properly designed, constructed, and managed landfills (Figure 21). Each of these activities requires careful planning, financing, collection.

Figure 20. Integrated waste management.

WASTE PREVENTION

Waste prevention also called ‘source reduction’ seeks to prevent waste from being generated. Waste prevention strategies include using less packaging, designing products to last longer, and reusing products and materials. Waste prevention helps reduce handling, treatment, and disposal costs and ultimately reduces the generation of methane.

RECYCLING AND COMPOSTING

Recycling is a process that involves collecting, reprocessing, and/or recovering certain waste materials (e.g., glass, metal, and plastics, paper) to make new materials or products. Some recycled organic materials are rich in nutrients and can be used to improve soils. The conversion of waste materials into soil additives is called composting. Recycling and composting generate many environmental and economic benefits. For example, they create jobs and income, supply valuable raw materials to industry, produce soil-enhancing compost, and reduce greenhouse gas emissions and the number of landfills and combustion facilities.

DISPOSAL (LAND FILLING AND COMBUSTION)

These activities are used to manage waste that cannot be prevented or recycled. One way to dispose of waste is to place it in properly designed, constructed, and managed landfills, where it is safely contained. Another way to handle this waste is through combustion. Combustion is the controlled burning of waste, which helps reduce its volume. If the technology is available, properly designed, constructed, and managed, landfills can be used to generate energy by recovering methane. Similarly, combustion facilities produce steam and water as a byproduct that can be used to generate energy.

PROBLEMS

1. Define Windrow Composting and explain the mechanism of Aeration for Windrow Composting
2. Explain the Plasma Gasification technique for treatment of Municipal Solid Waste with neat sketch.
3. If the recycling rate of aluminum can is 63%, calculate the energy required to produce the aluminum can of 355 ml capacity having weight about 16g. How much energy is saved, if a can is recycled instead of throwing away? Also estimate the amount of gasoline being wasted when one can is thrown away. Energy needed for conversion of 1 kg bauxite in to aluminum can is 17400 kCal. Assume the relevant data if needed.
4. A city of 1, 00,000 people generate 50,000 tonnes of MSW per year. If 22% generate MSW is recovered/recycling, 32% goes for composting and the rest goes to a landfill then.
   i) What lift area would be required per year
   ii) If the current landfill site covers 50 acres (1 acres = 4046.825 m2), including 10 acres needed for access roads and auxiliary facility, then estimate the life of this landfill. Consider the landfill density 900 kg/m3 and Cell depth as 3 m and 80% of the cell is MSW.
5. Design the windrow composting system for composting of degradable MSW for Indore Municipal Corporation (IMC). IMC generate about 750 TPD MSW and composition of MSW is as follows:

Degradable (%):	48.97
Recyclables (%):	12.57
Moisture (%):	31%
C/N ratio:	29.30
HCV (kCal/Kg):	1437
Moisture (%):	31%

Composting period may be considered as 50 days. Assume the relevant information if needed.

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Chapter 7

URBAN SOLID WASTE MANAGEMENT PROCESSES, IMPLICATIONS, THREATS AND OPPORTUNITIES: AN OVERVIEW ON RELATED ISSUES AND MITIGATION MEASURES

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ABSTRACT

Most of the cities in Indian cities show inefficiencies in environmentally sound and sustainable waste management. An audit on the performance of municipal solid waste (MSW) management undertaken by the Comptroller and Auditor General (CAG) of India in 2007 revealed that no states have completed a comprehensive data about waste volumes and composition. As stated, priority of reducing, recycling and reusing waste have been largely ignored while municipalities focus instead on disposal. The formal waste management system in most of the cities is started from households and ends up in landfills. Due to the tremendous increase in MSW generation with the adequacy of the land occupancy will also be alarming in the future in India. Moreover, dumping of MSW by improper manner in surrounds creates nuisance to the locality, environment as well as human health. Therefore, this is utmost required that of the hour is to turn the best out of waste, therefore waste minimization with adequate techniques and technologies have to be adapted to the Indian conditions. It has been assessed that the energy generation potential from the MSW reaching landfills in Indian cities, four available technologies, namely biomethanation, incineration, refused derived fuel (RDF) and plasma arc gasification. The result shows that different technologies for harnessing the energy from the MSW have different potentials. It has been found that the most cost effective and highest energy generation potential in biomethanation technique which has the potential

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of energy generation of 133-166 GW in the year 2040, moreover this technique is most adequate with the MSW composition in India.

Keywords: Urban solid waste management, implication, threats, mitigation measures

URBAN WASTE AND ITS TYPES

Waste is any material that is not useful or does not represent an economic value to its owner, the waste generator. The waste management is a very subjective term, since it depends on the point of view of the people involved during its generation, handling and treatment. Waste includes all items that people no longer have any use for, or which they either intend to get rid of or have already thrown away. Additionally, waste are such items which people are required to discard, probably because of their harmful effects to them. Waste can be classified by the state, i.e., solid and liquid. By the origin, the solid waste has been classified as Municipal solid waste (MSW), industrial waste, mining waste and hospital waste. MSW is generated by household, commercial and/or institutional activities. Industrial solid waste is generated by the industries during the use of raw materials in different industrial processes e.g., physical, chemical, biological, packaging, etc. Mining is the process that includes all the overburdens/crust removed in order to gain access to an ore, mineral or coal. Hospital wastes containing biomedical as well as hazardous substances produced at the hospital. The liquid waste is generated by the domestic and Industrial waste water discharge.

This chapter takes a practical approach to SWM in Indian cities. Its analyses of solid waste management system from cradle to grave approach that will help to understand the present scenario of solid waste management in developing country like India which includes:

- Dealing with driving forces in MSW generation
- MSW Generation in India and global estimation
- MSW management practices in Indian cities
- Future threats of MSW handling and management
- MSW minimization techniques with opportunities of non conventional energy generation: a potential assessment

MUNICIPAL SOLID WASTE MANAGEMENT IN INDIAN CITIES

Solid waste management is the effort of eradicating and disposing all the unwanted material through a cautious, planned and judicious use of available means to achieve an end. It comprehends the planning, financing, construction and operation of facilities for the collection, transportation, recycling and final disposition of solid waste. It is based on principles such as engineering, economics, public health, conservation, aesthetics, environmental, social and ethical issues (Shah, 2000). In most developed and developing countries with increasing population, prosperity and urbanization, it remains a major challenge for municipalities to collect, recycle, treat and dispose of increasing quantities of solid waste. Basically, the solid waste management system is formed by the following subsystems, or elements like (I) generation, (II) separation and storage at site, (III) collection, (IV) recycling, (V) processing and transformation of solid waste, (VI) transfer and transport and finally (VII) disposal. Figure 1 shows the MSW management framework.

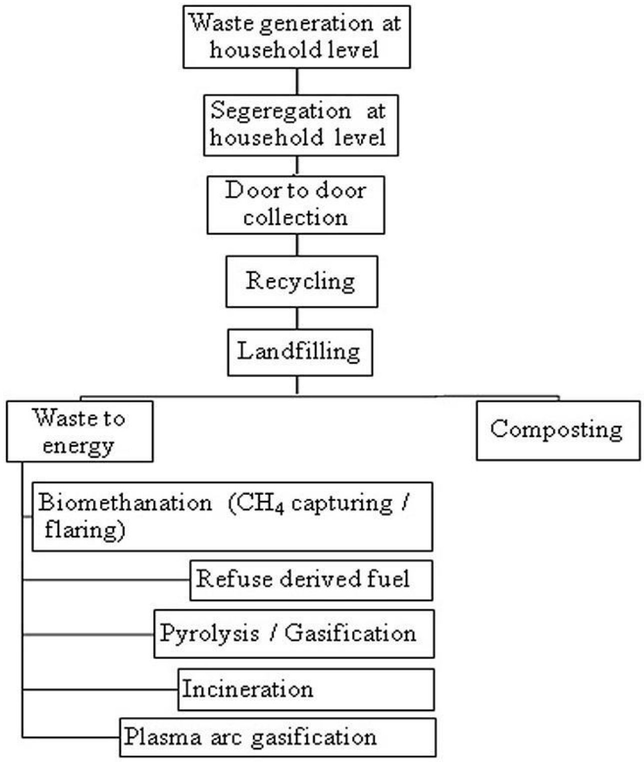


Figure 1. Framework of Municipal Solid Waste Management.

Municipal Solid Waste (Management and Handling) Rules, 2000

This is a basic requirement in the developing country like India that the municipalities should have a proper and scientific technique for MSW management, thus the MSW (Management and Handling) Rules, 2000 were notified by the Ministry of Environment and Forests, Government of India.

These rules were framed in order to make the municipalities well aware of their responsibilities so that they can implement the same. Municipal authorities must meet the deadlines laid down in Schedule-I (Table 1) of the rules and must follow the compliance criteria and procedure laid down in Schedule-II. Hence, municipal authorities are responsible for implementing the provisions of the year 2000 rules. They must provide the infrastructure and services in regards to collection, storage, segregation, transport, treatment and disposal of MSW. Where, the CPCB is responsible for coordinating the implementation of the rules among the state boards. The municipalities were mandated to implement the rules by

December 2003, with punishment for municipal authorities that failed to meet the standards prescribed; nevertheless, most municipalities did not meet the deadline. Municipal authorities are required to meet the specifications and standards specified in Schedules III and IV.

Table 1. Schedule for Municipal Solid Waste (Management and Handling) Rules- 2000

Schedule-I	Set up waste processing and disposal facilities before the end of year 2003 or earlier
	Monitor the performance of processing and disposal facilities at once in every six months
	Improve existing landfill sites as per the provisions of the rules before the end of year 2002 or earlier
	Identify landfill sites and make sites ready for operation before end of year 2002 or earlier
Schedule-II	Specifications relating to collection, segregation, storage, transportation, processing and disposal of MSW
Schedule-III	Specifications for landfilling indicating site selection, facilities at the site, specifications for landfilling, pollution prevention, water quality monitoring, ambient air quality monitoring, plantation at the landfill site, closure of the landfill site and post-care.
Schedule-IV	Indicates waste processing options, including standards for composting, treated leachate and incinerations.

Source: MoEF, 2000.

GENERATION OF MUNICIPAL SOLID WASTE

The availability and quality of annual MSW generation data are the major issues in the waste sector. Solid waste and wastewater data are lacking in many countries, data quality is variable, definitions are not uniform, and inter annual variability is often not well quantified (IPCC-AR4, 2007). There are three major approaches that have been used to estimate global waste generation data (i) from national waste statistics or surveys; (ii) by using several proxy variable linked to population, urbanization and affluence gross domestic product (GDP) as recommended by IPCC methodologies: and (iii) by using parameters like energy consumption and standard of living, etc. (Bingemer and Crutzen, 1987; Richards, 1989; Rathje et al., 1992; US EPA, 1999; Bogner and Matthews, 2003; OECD, 2004, Jha et al., 2008).

GLOBAL SCENARIO

Globally the estimated quantity of waste generation was 12 billion tons in the year 2002 of which 11 billion tons were industrial wastes and 1.6 billion tons were MSW (Pappu et al., 2007). About 19 billion tons of solid wastes are expected to be generated annually by the year 2025 (Yoshizawa et al., 2004).

Annually, Asia alone generates ~4.4 billion tons of solid waste, of which 790 million tons (Mt) is MSW, where about ~6% (48 Mt) of total annual MSW generated in Asia, is from

India (Yoshizawa et al., 2004; CPCB, 2000a). The solid waste generation rate ranges from <0.1 t/cap/yr (in low income countries) to >0.8 t/cap/yr (in high-income industrialized countries) (World Bank, 2005; Table 2).

Table 2. Comparison of the annual income with MSW generation rate

Country	High income	Middle income	Low income[#]
Annual income (US$/cap/yr)	825-3255	3256-10065	>10066
MSW generation rate (t/cap/yr)	0.1-0.6	0.2-0.5	0.3 to >0.8

[#] World Bank (2005; www.worldbank.org/data/wdi2005).

Sources: Bernache-Perez et al., 2001; CalRecovery, 2004, 2005; Diaz and Eggerth, 2002; Griffiths and Williams, 2005; Idris et al., 2003; Kaseva et al., 2002; Ojeda-Benitez; Huang et al., 2006; US EPA, 2003.

The IPCC-2006 guidelines' reported values of the yearly per capita MSW generation rate, fraction of disposing, treatment efficiencies, etc. by the continents are given in table 3 (IPCC, 2006). It is evident from this table that average per capita MSW generation rate in Asia is the lowest while the Oceania has the highest generation rate. Incineration of MSW is highest in the Asia and lowest in the South America. However, for Oceania and Africa, incarnation is not reported. MSW disposed to the respective solid waste dumping sites is reported to be 63% in Asia, 69% in Africa, 60% in Europe, 58% in North America, 54% in South America and 85% in Oceania (IPCC, 2006; Table 3).

Table 3. MSW generation, disposal and treatment by the continents, global scenario

Continents	MSW Generation Rate (ton/cap/yr)	Fraction of MSW disposed to SWDS	Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified
Asia	0.28	0.63	0.18	0.04	0.22
Africa	0.29	0.69	-	-	0.31
Europe	0.57	0.60	0.17	0.09	0.13
N. America	0.65	0.58	0.06	0.06	0.29
S. America	0.26	0.54	0.01	0.003	0.46
Oceania	0.69	0.85	-	-	0.15

Source: IPCC 2006; Note: Solid waste dumping sites (SWDS)

INDIAN SCENARIO

MSW generation in urban centers has been estimated by a group of researchers (Chakraborty et al., 2014; Annepu, 2012; MoEF, 2010; Kumar et al., 2004; Pachauri and Sridharan, 1998). The per capita per day (PCD) MSW generation rate has been estimated at 0.5–0.7 kg (Kameswari et al., 2003). However, the PCD MSW generation is directly associated with the economic growth of the country and the total MSW generation is associated with the urban population of the country (Jha et al., 2008). Total MSW generated in Indian cities have increased from 48 × 10^3 Gg in 1997 (Pachauri and Sridharan, 1998) to 70.8 × 10^3 Gg in 2007 (MoEF, 2010). Whereas, MSW generated by the Indian cities was estimated by CPCB (2004) as 24 x 10^3 Gg in 1991 and more than 39 x 10^3 Gg in 2001. Kumar et al., (2004) reported MSW generations from Indian cities as 23 x 10^3 Gg in 1999. Whereas, a recent study by Annepu (2012) reveals that the generation of MSW from Indian cities was 68.8 x 10^3 Gg in the year 2011. Chakraborty et al., (2014) estimated this value as 572 Gg for the year 2011 by using the state wise MSW generation rate, collection efficiencies of municipalities, recycling efficiencies and MSW composition.

STORAGE AND SEGREGATION OF MSW

Storage of waste at source is the first step of MSW management. Every household, shop and establishment generates solid waste on day to day basis. The waste should normally be stored at the source of waste generation till it is collected for its disposal. The temporary storage stage is a responsibility of the waste generation source and its objective is to keep the waste temporally stored in at least two separate bins (one for biodegradable waste and other for recyclable waste; Zhu et al., 2008).

In India, Municipal authorities and some non-government organizations have been trying to educate and create awareness in urban population about waste disposal. However, there is now a new push for creating awareness about waste collection, disposal and cleanliness under the newly launched ambitious programme of "Swachh Bharat Abhiyan (i.e., Clean India Mission)" of the Government of India.

COLLECTION OF MSW

The system of primary collection or storage of waste at source is practically yet to be developed. Doorstep collection of waste from households, shops and establishments is insignificant and wherever it is introduced through private sweepers or departmentally, the system does not synchronize further with the facility of waste storage depots and transportation of waste (CHEEPO, 2000). The solid waste is generally stored in local dustbins, sometimes either on the ground outside the dustbin or thrown away to the streets. Thus streets are generally treated as receptacles of waste and the primary collection of waste is done, by and large, through street sweeping. An appropriate system of the primary collection of waste is to be so designed by the urban local bodies that it synchronizes with storage of waste at source as well as waste storage depot facility ensuring that the waste once collected reaches the processing or disposal site through a containerized system (CHEEPO, 2000).

Collection vehicles must meet the requirements of local conditions. Generally an assessment of the housing situation, street conditions, and geographic and topographic situation is always a requirement for efficient planning and decision making for primary collection equipment. In general, primary waste collection can be done with slow and smaller vehicles, which do not need to cover very long distances like handcarts, tricycles and rickshaws, motorized rickshaws, tractors with trailers. Door to door collection by motorized vehicle has been seen in some big cities like Delhi, Mumbai, Ahmadabad, Chennai, Kolkata, Lucknow, Chandigarh, etc. (Asnani, 2006).

RECYCLING OF MSW

Though the labor cost is lower in the developing countries, the expenses incurred on waste management can constitute a larger percentage of municipal income because of higher equipment and fuel costs (Cointreau-Levine, 1994). Many developed countries had initiated comprehensive recycling programs towards the end of 1990. It is important to recognize that the percentage recycling, composting, incinerating or landfilling of MSW differ greatly amongst municipalities, due to multiple factors, like local economics, national policies, regulatory restrictions, public perceptions and infrastructure requirements. A large amount of recyclables are separated out from MSW (by the informal recycling sector) prior to and after landfilling. The European Union (EU) recycled 17% of its MSW in 1995 and 40% in 2008. In that period, the landfill share of waste dropped from 68 to 40% (EEA, 2011). However, in England most of the MSW ends up in landfill sites; only 19% of household waste is currently recycled or composted (Postnote, 2005). The recycling rate in USA of 34.1% (*i.e.*, 85 Mt) in 2010 where the recyclable items consist of auto battery (96.2%), newspapers/mechanical papers (71.6%), steel cans (67.0%), yard trimmings (57.5%), aluminium cans (49.6%), tires (35.5%), glass containers (33.4%), PET bottles and jars (29.2%), HDPE (white translucent) bottles (27.5%), etc. (USEPA, 2010).

In India, the consumption rate of plastic and paper was ~5.2 and ~6.2 kg/capita/y respectively for the year 2011; therefore the generation can be estimated that 6.14 and 7.5 Mt of respectively (Gupta et al., 1998, Upadhayay et al., 2005). The plastic demand growth is about 22% per annum, having a present consumption rate of about 2 kg capita^{-1} yr^{-1} against the Asian average of about 10 kg capita^{-1} yr^{-1} (Upadhayay et al., 2005). India recycles 40% of its plastic waste compared to a figure of only 15-20% in the developed world (Pachauri and Sridharan, 1998). Whereas, recycling efficiency of waste paper is about 29% against a global average of 36% (Sharma et al., 1996). The recovery rate is about 14% against a global average of 37% (Upadhyay et al. 2005). Waste recycling rate is 10-15% of apparent consumption in low-income countries against 30 to 75% in OECD (The Organization for Economic Co-operation and Development) countries (OECD 2002).

The amount of recyclable separated by the informal sector after the formal collection is as much as 21% (Annepu, 2012). The amount of recyclable separated prior to the collection is generally not accounted by the formal sector and could be as much as four times of the amount of recyclable separated after formal collection. It has been also observed that the percentage of collection of recyclable in MSW by the informal sector has increased in metros and other large cities (Annepu, 2012). The presence of informal sector in large cities explains the huge difference in recyclable composition between large and small cities as observed by Bhada and Themelis, (2008). It has been observed that the major class I cities have a vigorous presence of the informal recycling sector. The amount of recyclable at the dumped MSW in big cities is 16.3%, whereas in smaller cities the amount of recyclables in the dumped MSW is 19.2%. The difference of 3% in the amount of recyclable indicates the higher number of waste pickers and their activities in larger cities (Annepu, 2012).

TRANSPORTATION OF MSW

The average collection efficiency of MSW in Indian cities and states is about 70% only (Rathi, 2006; Siddiqui et al., 2006; Nema, 2004; Gupta et al., 1998; Maudgal, 1995; Khan, 1994). The collection efficiency is high in the cities and states, where private contractors and NGOs are employed for the collection and transportation of MSW. Most of the cities are unable to provide waste collection services to every part of the city. Transfer stations (except in a few cases as in Chennai, Mumbai, Delhi, Ahmedabad and Kolkata) are not used, and the same vehicle, which collects refuse from individual dustbins, takes it to the processing or disposal site (Colon and Fawcett, 2006; Khan, 1994). The MSW collected from dustbins and collection points is transported to the processing or disposal sites using a variety of vehicles. In smaller towns, bullock carts, tractor-trailers, tricycles, etc., are mainly used for the transportation of MSW. Light motor vehicles and Lorries are generally used in big towns or cities for transport of MSW. The trucks used for transportation of MSW are generally of an open body type and are usually kept uncovered; thus, during transportation, the waste tends to spill onto the road resulting in unhygienic conditions. In some cities, modern hydraulic vehicles are gradually being introduced (Bhide and Shekdar, 1998; Reddy and Galab, 1998).

BOX 1. AN EXAMPLE OF FORMAL AND INFORMAL MSW MANAGEMENT PRACTICES IN INDIAN CITIES

Most of the cities in India show inefficiencies in environmentally sound and sustainable waste management (Chintan, 2009). An audit on the performance of waste management undertaken by the Comptroller and Auditor General (CAG) of India in 2007 revealed that no states have completed a comprehensive data about waste volumes and composition. As stated priority of reducing, recycling and reusing waste have been largely ignored while municipalities focus instead on disposal.

The formal waste management system in most of the cities started from households and ends up in landfills where all types of waste (mixed household, commercial, institutional, etc.) either has been collected from door to door by waste collectors from municipal or thrown away into the designated dustbin by the households. From there the waste is collected by municipal person and dumped into the landfill. Beside the formal management, informal management system is also thriving in large cities of India mainly comprising of recycling activities.

The number of workers in this sector are roughly 10,000-100,000 people which consists of wastepickers, small kabaris (i.e., small businessman of recyclable material), thiawalas (i.e., waste collectors), and big kabaris (i.e., big businessman of recyclable material) (Annepu, 2012; Chintan, 2009; Asnani, 2006). The relationship of the informal sector to overall MSW management is best explained by the following figure 2.

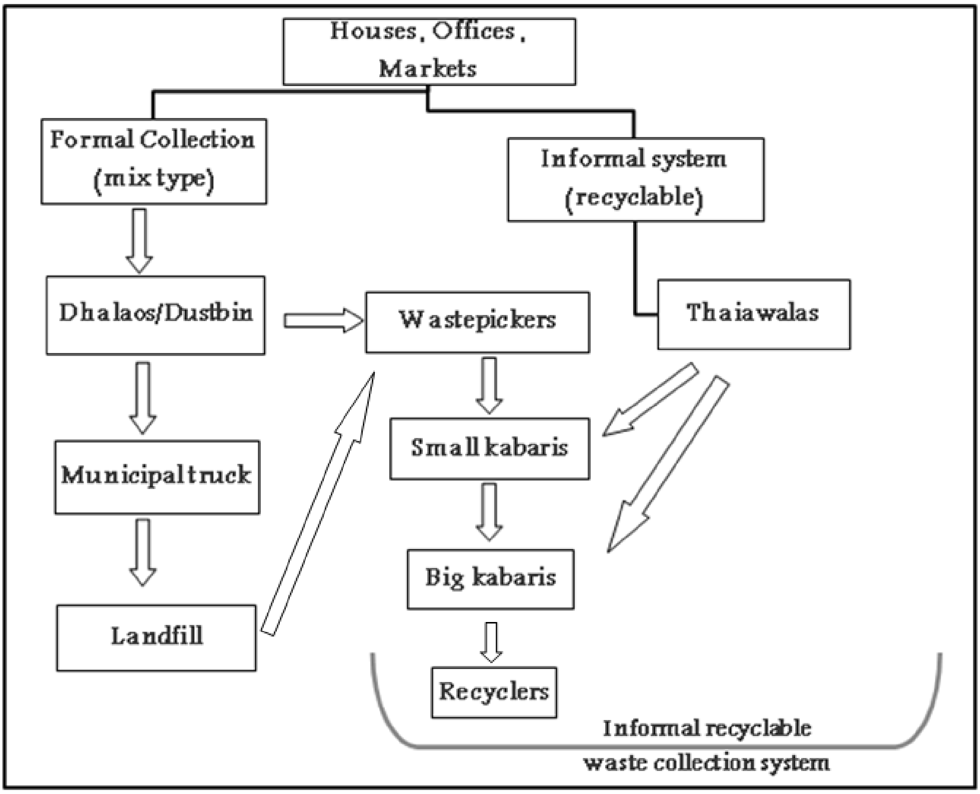


Figure 2. MSW processing chain involving formal and informal systems.

Collection and transportation activities constitute approximately 80–95% of the total budget of MSW management (MSWM); hence, it forms a key component in determining the economics of the entire MSWM system. Municipal agencies use their own vehicles for MSW transportation, although in some cities these are hired from private contractors (Ghose et al., 2006; Siddiqui et al., 2006; Nema, 2004; Bhide and Shekdar, 1998).

DISPOSAL OF MSW

The generated MSW in urban areas is predominantly managed by depositing it in the low lying areas, called landfills. As landfilling is a low cost management option, it is the most popular mode of waste management. In India the most common disposal method applied to 70-90% of MSW are open dumping (Joseph et al., 2003) and the rest is dumped in properly managed landfills, unlike the case of landfills in developed countries. The Indian Municipal Solid Wastes (Management and Handling) Rules, 2000 states that, "Landfilling shall be restricted to non-biodegradable, inert waste and other waste that are not suitable either for recycling or for biological processing". Technically Landfilling is the oldest and most widely practiced waste disposal option. Modern landfill sites in India are also being developed from the old uncontrolled dumping sites using the advanced treatment and disposal options. In addition, modern purpose-built landfill sites incorporating a system for the extraction of landfill gas (arising from the decomposition of bio reactive wastes) from which energy can be recovered are also being developed. In the present scenario, types of wastes which is disposed in landfills include biodegradable wastes, aqueous liquids in limited amounts, inert wastes, and certain special wastes that would not pose toxic threats. Wastes that are generally considered unsuitable for landfilling include volatile liquids or solvents, wastes that would introduce unacceptable contamination into the leachate, and wastes that would interfere with the biological processes in a landfill site.

MSW Treatment Facility in India

In developed countries, a current goal is to decouple waste generation from economic driving forces such as GDP for reducing the waste generation (OECD, 2003; Giegrich and Vogt, 2005; EEA, 2005). In India, the treatment option that is widely accepted and also suitable for Indian MSW is composting (Asnani, 2006). Though other treatment options, which include incineration, palletization, biomethanation and vermicomposting are also adopted in 79 cities in India. Table 4 provides the summary of the MSW treatment facilities available in India based on the available literature (Annepu, 2012; CPCB, 2012; Asnani, 2006; CPCB, 2000a and 2000b; CPCB, 2004; Sharholy et al., 2006; Gupta et al., 2007; Kumar et al., 2009; Sharholy et al., 2008; Bhatnagar and Basak, 2004; Ramakrishna, 2004; NSTEDB, 2008, Saxena et al., 2010). If all the processing and treatment plants are working properly, then a total of 5906 Gg/y of MSW can be treated in India using the available treatment facilities.

Table 4. MSW treatment facilities in India

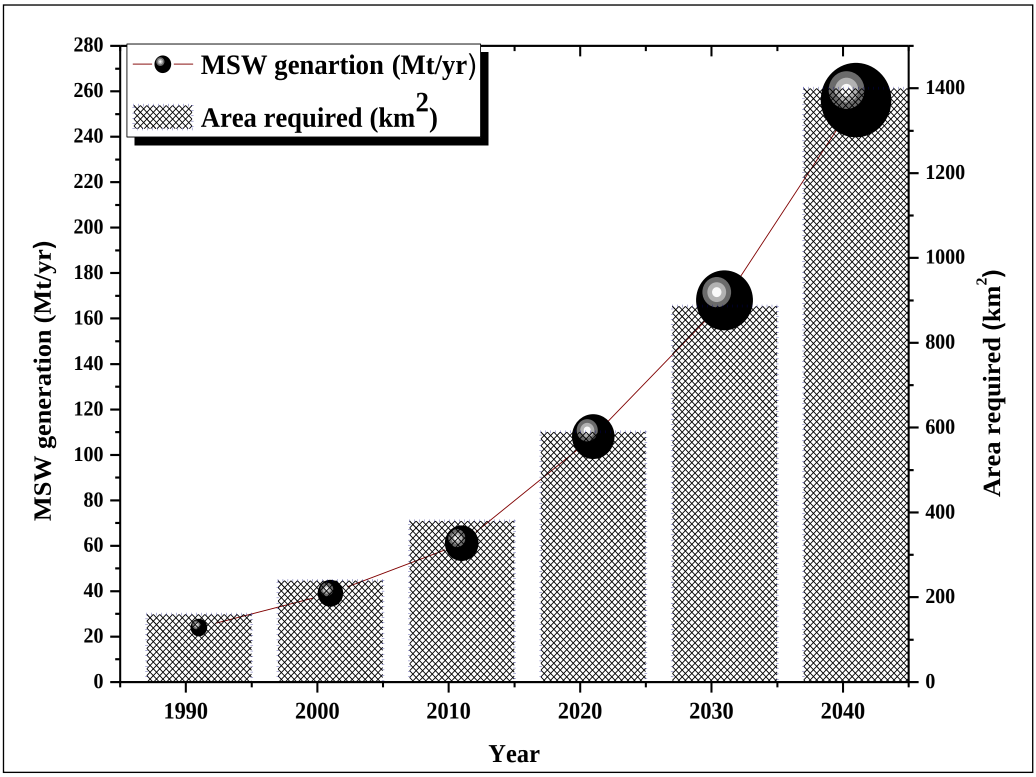
Processes	No. of Plants	Waste reduction capacity (TPD)	Annual waste reduction (Gg)
Composting & Vermicomposting	356	7513	2742
Biomethanation	21	1915	699
Incineration[&]	1	300	109
RDF	8	2580	942
LFG recovery	6	3873	1414
Total	401	16181	5906

Source: Chakraborty et al., 2014.

MSW Is Serious Threat to Developing Country Like India

The fast growing population, rapid growth in the urbanization and changing food habits in urban clusters are resulting in the exponential growth in MSW generation. Singhal and Pandey, (2001) stated that due to tremendous increase in MSW generation, the adequacy of the land for landfills will be alarming in future in India. They calculated that the waste generated in 2001 would have occupied 240 km^2 or an area half of the area of Mumbai; waste generated in 2011 would have occupied 380 km^2 that is equivalent to 90% of area of Chennai while the waste generated by 2021 would need 590 km^2 which is greater than the area of

Hyderabad (Singhal and Pandey, 2001). The `Position Paper on The Solid Waste Management Sector in India', published by Ministry of Finance (Department of Economic Affairs, 2009) estimated a requirement of approximate 1400 km^2 of land for solid waste disposal by the end of 2040 if MSW is not properly handled which is almost equal to the area of the State of Delhi. Figure 3 shows the MSW generation rate and the required areas in India during 1990 to 2040 periods.



Note: Mt = 106 tons or 103 Gg

Figure 3. Estimation of MSW generation and required area for its disposal in India.

Landfills have been identified as one of the major threats to groundwater resources (Fatta et al., 1999; US EPA, 1984). Waste placed in landfills or open dumps are subjected to either groundwater underflow or infiltrated by the precipitation. The dumped solid wastes gradually release its initial interstitial water and some of its decomposition by-products get into the water moving through the waste deposit. Such liquid containing innumerable organic and inorganic compounds is called 'leachate' which accumulates at the bottom of the landfill and percolates through the soil. The surrounding areas near to the landfills are more prone to groundwater contamination due to leachate which is the potential pollution source of ground water.

Due to the presence of high quantities of contaminants *viz.* cadmium, lead, chromium, copper, fluoride, nitrate, phosphate, chloride, etc. in groundwater, this source poses a substantial risk to local resource user and to the natural environment.

The impact of landfill leachate on the surface and groundwater has attracted a number of studies in recent years in India (Mor et al., 2006; Rawat et al., 2008; Cumar and Nagaraja, 2011; Bhalla et al., 2012; Goswami and Choudhary, 2013; Archana and Dutta, 2014; D'Souza and Somashekar, 2013).

MSW mainly comprises of biodegradable materials, which decompose via a complex series of microbial and abiotic reactions resulting in methane (CH_4) and carbon dioxide (CO_2) formation as terminal products together with small quantities of non-methane organic compounds and other trace gases (Hegde et al., 2003). Both CH_4 and CO_2 are potent greenhouse gases (GHGs). The global warming potential (GWP) of CH_4 is 25 times of the GWP of CO_2 and the CH_4 has an atmospheric residence time of 12±3 years over a time period of 100 year scale (IPCC, 2007). The current contribution of CH_4 to climate change forcing is 18% of the total radiative forcing from all long-lived greenhouse gases (Forster et al., 2007).

Global anthropogenic methane production has been estimated as 550±105 x 10^3 Gg (Mendelsohn and Roseberg 1994), while the landfills have been estimated to contribute 16 to 22 x 10^3 Gg (Bogner and Matthews, 2003; Simpson et al., 2006). Earlier, it was estimated that CH_4 emitted from landfills contributes approximately 10% of the annual increase in the atmospheric CH_4 content (Reeburgh, 1996).

ENERGY GENERATION POTENTIAL OF MSW IN INDIA

There are several technologies which could be used for energy generation from MSW, among them four technologies viz. (i) biomethanation, (ii) Incineration, (iii) refuse derived fuel (RDF) and (iv) plasma arc gasification are widely used. A comparison of available waste treatment technologies (viz. biomethanation, incineration, RDF & plasma arc gasification) in respect of land requirements, technological efficiencies, capital cost, operating cost of the plants, types of waste to sustain plants, etc. based on the available literature is given in Table 5 which shows that though biomethanation technology requires less area (computed based on 2000 TPD MSW capacity only) than the other technologies during installation, in the long run it requires a huge land area.

The installation cost of plasma arc gasification technology is quite higher than the other technologies, but net energy production is highest by this technology, whereas installation cost of RDF plant requires minimal cost. All technologies require source separated waste except the plasma arc gasification technique, which can accept all types of waste including non biomass solid waste. Operational cost is minimal in RDF technology followed by plasma arc gasification, biomethanation and incineration. The energy generation potentials of these technologies have been discussed below:

Table 5. Inter comparison of WTE technologies

Technologies	Land requirement (Ha)/2000 TPD	Capital cost Rs. Crore	Cost of power generation (Rs./kWh)	Type of waste acceptance	Net Energy Production (kWh/100 t MSW)	Power generation Capacity (MW)	Operating cost (Rs./t of waste)
Biomethanation	6	180-200	4.9	Source separated waste only	-	30-40	<550
Incineration	6-16	130-140	2.8	All Waste since air cleaning technology is good	544	20-30	>5460
RDF	16-20	110-120	-	Inert segregated waste only	-	60-70	<500
Plasma arc Gasification	14	600-700	4.1	All waste is Acceptable	816	80-90	-

Source: Chakraborty et al., 2013.
Note: (-) data is not available.

Biomethanation

The CH_4 generation potential from MSW generated in cities of India has been estimated by LandGEM model (landfill Gas Emissions Model, Version 3.02, USEPA). When MSW is dumped in the landfills, LFG is generated in proportionate order with its organic content. The user specified input values have been used in LandGEM model. The input parameters like degradable organic carbon (DOC) for different types of waste materials have been used as provided by the IPCC default values on the wet waste basis (IPCC, 2007). The fraction of DOC (i.e., DOC_f) has been considered as 0.77 based on expert judgement. Using the analyzed composition of MSW of Delhi's landfills, CH_4 generation potentials (L_0) for the MSW have been calculated as 79.3 m^3/t of MSW (Chakraborty et al., 2013) based on the fact that segregation of organic waste like cotton, cloths, cardboard, paper etc. takes place by the rag pickers in India prior to MSW dumping in landfills. The value of MSW decay constant (*k*) has been used as 0.09 per year on the basis of tropical type of climate from the range of values given in the IPCC-2006 methodology. The percent volumes (*F*) of CH_4 and CO_2 in LFGs are considered to as 50% for each of these and the MCF value was used as 0.4.

The LFG generation has been estimated using the LandGEM model whose output shows the CH_4 and total LFG emissions of 419 and 839 Mm^3 in 2014 respectively (Fig.4). The future CH_4 and total LFG emissions have been computed as 1150 and 2300 Mm^3 respectively for the year 2040. The corresponding energy generation potential for biomethanation process has been estimated as 48-60 GW (Gigawatt) for the year 2014. The generation potential is expected to be 133-166 GW in the year 2040.

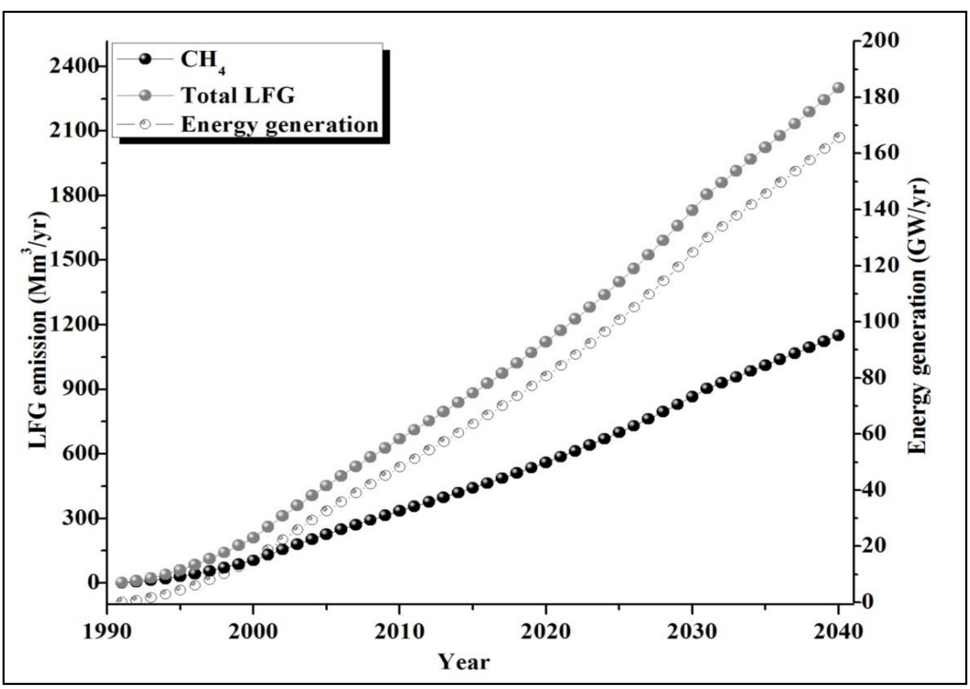


Figure 4. Energy generation potential of biomethanation of MSW.

The average density of the fresh MSW has been found to be 366 ± 115 kg/m^3 which increase to 720 ± 128 kg/m^3 on compaction, after exclusion of recyclable and inert materials (Chakraborty et al., 2013). This means that total space required for landfilling would be in the range of 2000–3000 m^2/d (where the height of deposition is taken as 1 m) for dumping of 1500–2000 TPD MSW. It amounts to almost 6 Ha and 110 Ha areas are required for the dumping of MSW for 20 days and one year respectively. CH_4 emission starts after 20 days of anaerobic decomposition (Griffin et al., 1998). MSW is required to be covered by the polyethylene sheet to create anaerobic condition for LFG generation and that cover cannot be opened for at least next 4–7 years to get optimum energy generation potential as the half-life of waste is 2–3.5 years in tropical climate (Wangyao et al., 2009; Machado et al., 2009). After 4–7 years, the biomethanation process becomes unviable due to low carbon content in the remaining waste. Therefore, the huge space is required to run biomethanation plants for treatment of the city's MSW generation.

Incineration

The incineration process is a potent technology which can reduce the waste volume up to 90% (Cheng and Hu, 2010) and the capital cost of this process is lower than the cost of biomethanation process. In order to estimate energy potential of the incineration process in Delhi's MSW, calorific values of Delhi's MSW samples have been derived using a bomb calorimeter. The calorific values have been found to be 1198–2602 kCal/kg for the bulk waste (excluding plastic, rubber, wood chips and packing and other inert materials). During this analysis, the moisture contents of sun-dry MSW samples have been measured as 2–5%. Using these calorific values, the energy generation potentials of MSW reaching to landfills were found to be 33-73 GW in 2014 which is expected to increase to 74-161 GW in 2040. The main disadvantage of this technology is the high recurring cost of around Rs. 5460/ton of waste processing where in approximately 80% of this cost is incurred on the fuel for burning the waste (MGBEPS, 2012). To sustain this technology, the minimum 1455.5 kCal/kg calorific value of MSW is required, which is often difficult in Indian conditions due to the presence of high moisture and inert materials in MSW. Additionally, the higher carbon containing materials of MSW are removed by the rag pickers as discussed earlier. Other major concern associated with this technology are the emissions of toxic gases like polychlorinated biphenyl (PCBs), hydrogen chloride (HCl), hydrogen fluoride (HF), mercuric chloride (HgCl), dioxins ($C_4H_4O_2$) and furans (C_4H_4O) which are considered to be harmful to human health and environment.

Refuse Derived Fuel (RDF)

This is one of WTE process where installation costs as well as maintenance costs are lowest among all the available methods. There are several benefits associated with this technology which include its higher heating value (2994–4006 kCal/kg) that remains fairly constant in the presence of 3–8% moisture content (Sikka, 2000), the homogeneity of physico-chemical composition, the ease of storage, handling, and transportation, the lower pollutant emissions and a reduced excess air requirement during combustion (Cheng et al., 1998; Saxena and Rao, 1993; Gupta and Rohrbach, 1991). The high calorific value of RDF is due to its higher density (~700 kg/m^3) compared to the other forms of waste.

It has been estimated that 160 ton of garbage produce 40 ton of pellets (Sikka, 2000). In this process, segregation of materials like inert, plastic, packing, etc. by air or mechanical separator is carried out to minimise the emissions of harmful gases. This technology is considered as relatively clean. This technology has a potential to generate electricity in the range of 23-30 GW in 2014 from the segregated waste which is expected to increase to 50-70 GW in 2040.

Plasma Arc Gasification

Plasma is often called the fourth state of matter containing a significant number of electrically charged particles. In this process, waste materials are gasified via pyrolysis inside a special stubborn lined reactor. A plasma arc torch increases the temperatures in the reactor gasification vessel to as high as 3300–6000 ºC which may even go as high as 15,000 ºC (Zhang et al., 2010; Makled and Grotke, 2008). The two processes viz. gasification by means of partial combustion with oxygen [$C_6H_{10}O_4 + 3O_2 = 3CO + 3CO_2 + 4H_2 + H_2O$ + 54 kW (assuming zero reactor heat loss)] and gas turbine combustion with sufficient oxygen [$3CO + 4H_2 + 3.5O_2 = 3CO_2 + 4H_2O$ + 62.5 kW (assuming no turbine heat loss)] produce high energy from per unit quantity of MSW. Though the average efficiency of this technology has been reported as 42% by Janajreh et al. (2013), Chakraborty et al. (2013) have assumed an average efficiency of 25%. Using this value, the plasma arc gasification technology is estimated to have electricity generation potential in the range of 23-44 GW from the bulk waste in 2014 which is expected to increase to 51-93 GW in the year 2040 (assuming utilization of completely dry MSW).

CONCLUSION

The waste minimization with optimized management techniques, the 4 R's *viz*. Reduce, Reuse, Recycle and Recover have to be adopted. Waste includes all items that people no longer have any use for or which they either intend to get rid of or have already discarded. Additionally, waste are such items which people are required to discard, probably because of their hazardous properties. Many items can be considered as waste e.g., household rubbish, sewage sludge, waste from manufacturing activities, packaging items, garden waste, etc. Thus, all our daily activities can give rise to a large variety of different waste arising from different sources. The need of the hour is to manage and dispose the waste in environmentally sustainable manner and extract the best out of waste. Therefore, waste minimization using appropriate techniques and technologies need to be adopted which best suited to Indian conditions. To assess the energy generation potential from the MSW reaching the landfills in Indian cities, four available technologies, namely biomethanation, incineration, refused derived fuel (RDF) and plasma arc gasification have been investigated. The result shows that different technologies for harnessing the energy from the MSW have different potentials. The biomethanation technology shows the highest potential for energy generation and is estimated to have potential to generate energy in the range of 133-166 GW in the year 2040. This is followed by Plasma arc gasification, Incineration and RDF which are found to have energy generation potential in the range of 51-93 GW, 37-81 GW and 50-67 GW respectively in the year 2040. Thus, the biomethanation technology seems to have highest energy generation potential, but a number of factors and other issues like land required, capital cost for installation, handling of by-products, environmental regulations, etc. are required to be considered for identifying the viable and most suitable technologies for WTE. The potential energy generation values quoted here are based on theoretical ideals and are indicative in nature.

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Chapter 8

SUSTAINABLE APPROACH TO WASTE MANAGEMENT- VERMICOMPOSTING TECHNOLOGY

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ABSTRACT

Solid waste disposal and management is a challenge for scientists, municipalities and governmental agencies all over the world. Various solid waste management methods are available but all methods have their own benefits and limitations. So scientists are continuously working for the development of ecologically sustainable and economically cheaper strategies. In yesteryears several new biological approaches for solid waste management have been developed including biomethanation, bioremediation, microbial enzyme solutions, vermicomposting, composting etc. In this chapter, a review of vermicomposting process, different process variables, suitable earthworm species, effective waste management and potential application of the product to the plants is presented.

Keywords: Vermicomposting, organic waste, earhtworm, *Eisenia fetida,* plant nutrients, NPK, epigeic

INTRODUCTION

Anthropogenic activities generate huge quantities of solid wastes of highly heterogeneous composition. The disposal and management of such wastes is a technical and ecological challenge throughout the world mainly due to their nature. In India, the per capita solid waste generation is estimated to increase at a rate of 1-1.33% annually (Shekdar, 1999). As a result, the total waste quantity generated in 2047 would be approximately 260 million tons which is

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more than five times the present level. In addition to household solid waste, agricultural and dairy activities, sewage biosolids, and industries generate large quantities of organic wastes. Most of it ends up in open dumps along road sides or unscientific landfills in low lying areas in the periphery of the urban centres which may contaminate surface and ground water and pose health hazards. It has been estimated that 50-60% fraction of the solid waste is organic in nature. Open dumping and open burning of such waste may lead to spread of vector borne diseases and air pollution in surrounding areas. These unscientific disposal practices also lead to loss of the valuable nutrients contained in these organic wastes.

An attractive alternative for the management of such solid wastes is composting because it is cost effective in comparison to land filling or incineration. Composting is the aerobic process in which heterotrophic microorganisms (mesophilic and thermophilic) decompose organic matter and produce a stabilized product called as compost. Decontamination of the composts is achieved through early thermophilic phase of composting, when temperatures reach up to 70^{o}C. During the mesophilic phase remaining organic compounds are degraded at a slow pace in a process similar to humification in soils. The process can effectively reduce the waste volume by 40-50%. It has gained importance in recent years as a suitable option for waste management as it is easy to operate and can be performed in limited space. The major limitations associated with composting are longer duration of the process, loss of nutrients during the process, frequent turning of the waste material for aeration etc (Nair et al., 2006; Ndegwa and Thompson, 2001).

In recent years, many researches and reports have proved the potential of earthworms and microorganisms jointly for waste decomposition in a process named vermicomposting (Figure 1). These organisms transform organic waste into humus like product called as vermicompost which is rich in various plant nutrients, viz., nitrogen, potassium, phosphorus etc. It is one such technology which can be used at small (household level) to very large (several households, village or an entire city) scale. In this chapter, the vermicomposting process, which could provide an efficient solution, to tackle the problem of safe disposal of waste, as well as the most needed plant nutrients for sustainable soil productivity has been described in detail with present state of research in this field.

Figure 1. Large scale vermicomposting.

THE VERMICOMPOSTING PROCESS: AN OVERVIEW

Vermicomposting is the conversion of organic materials into humus like material known as vermicompost or vermicast. The process involves bio-oxidation and stabilization of organic matter through the joint action of earthworms and microorganisms in an aerobic environment. The end product, i.e., vermicompost is rich in humus and plant and is considered as environment friendly organic manure for agricultural applications (Tajbakhsh et al., 2011). The vermicomposting process can be divided into two phases based on the earthworms activities: 1) the direct vermicomposting phase, in which earthworms ingest, digest and assimilate the organic materials and modify their physico-chemical and microbial properties; and 2) the indirect maturation phase, in which microorganisms already present in the feedstock or propagated under the existence of earthworms decompose the processed materials till the end even after the earthworms are removed from the process (Dominguez et al., 2010). In this process, earthworms break down the organic matter into small fragments during their ingestion. The ingested materials are grinded by gizzard of the earthworms and increase its surface area. Then, it passes to the intestine of the worm and decomposed by various enzymes present in the intestine as well as by the enzymes of the ingested microorganisms (Hand et al., 1988). As a result, the complex compounds present in the waste material are converted into simpler ones and in turn, the plant nutrients contained in the material such as NPK etc. are transformed into more soluble and available forms to plants than the parent organic material (Ndegwa and Thompson, 2001).

Various studies have revealed that earthworms promote the microbial activity and population during decomposition of organic materials (Sen and Chandra, 2009; Castillo et al., 2013; Vivas et al., 2009 and Gomez-Brandon et al., 2013). Huang et al. (2014), in a vermicomposting study, investigated through quantitative polymerase chain reaction (PCR) that the presence of earthworms enhanced the bacterial and fungal populations, and modified their communities. In addition, denaturing gradient gel electrophoresis (DGGE) combined with sequencing analysis revealed that earthworms modified the bacterial and fungal community structures, through broadening the diversities of actinobacteria, bacteroidetes, proteobacteria, and ascomycotina. They concluded that the final quality of the vermicompost is the result of combined efforts of earthworms and the microorganisms.

In a similar study, Castillo et al. (2013) monitored the variations in the microbial structure, relative abundance of four bacterial classes and fungi over the vermicomposting and maturation period of wet olive cake (O) and vine shoots (W) through quantitative PCR and DGGE analysis. They found that although *Eisenia fetida* development was different in both the wastes, significant correlations were found with *b*-glucosidase activity and with bacterial and fungal structure. In the vermicomposting period of O and W, a decline was found in bacteria (94% and 77%), fungi (93% and 94%), and Gamma-proteobacteria (56% and 71%) but an increase in *beta*-proteobacteria and Actinobacteria (62–79%). Alpha-proteobacteria increased only in O (26%). Despite the different initial lignocellulose wastes, the mature vermicomposts were similar in microbial and biochemical properties. The maturation period resulted in a reduced microbial activity while the total abundance increased. The researchers related the presence of Actinobacteria as good indicators to ensure the safety of the vermicomposts, although they recommended further studies in this area.

Further, Kale and Krishnamoorthy (1981) have reported that earthworms act as sanitizer in the processing of the wastes. The earthworms release coelomic fluids in which mucocytes, vacuolocytes, granulocytes and lymphocytes are present which kill the bacteria and parasites present in the waste, thus, making the vermicompost odor and pathogen free. Significantly, the vermicompost is considered an excellent product of homogeneous and odor-less nature, rich in microflora, and tends to hold more plant nutrients over a longer period.

VARIOUS STAGES IN THE VERMICOMPOSTING PROCESS

A large variety of the organic wastes from agriculture, industry and domestic origins can be gainfullly vermicomposted provided that these are non-toxic to earthworms. The vermicomposting process takes place mainly in the mesophilic temperature range (20 - 35^{o}C). It is suggested that pre-treatment and pre-composting of organic waste should be done to avoid mortality of worms as well as to get good quality vermicompost. Broadly, the whole process falls into four stages:

a) Pre-decomposition stage: The pre-decomposition of organic waste prior to vermicomposting is essential to make them acceptable to worms. There are many organic wastes which cannot be directly used as a feedstock for earthworms due to the presence of some toxic substances (Kaplan et al., 1980). These toxic substances in the feed can be excessive heat, urine, inorganic salts, ammonia, alkali, alcohol, methane gas, etc. (Dominguez and Edwards, 2004; Edwards, 2007; Gunadi and Edwards, 2003). Some examples are sewage sludge (Gupta and Garg, 2008), fresh human faeces (Yadav et al., 2010), anaerobic digestion waste (Elvira et al., 1997; Garg et al., 2005), biogas slurry (Garg et al., 2006), etc. The pre-decomposition stage mainly includes precomposting and turning in natural conditions. The optimum time for this stage generally ranges between 7 to 20 days depending on the type of waste. During this phase, readily decomposable compounds are degraded and the potential volatile substances are eliminated which may be toxic to earthworms. Gunadi and Edwards (2003) have reported the death of *Eisenia fetida* after 2 weeks in the fresh cattle solids although all other parameters were suitable for the growth of earthworms. They attributed the death of earthworms to the anaerobic conditions which developed in fresh cattle solids.

During pre-decomposition, the organic waste can be decomposed with microorganisms naturally present in the wastes or the process can be accelerated by inoculation of microorganisms (Singh and Sharma, 2002; Kumar et al., 2010a). Kumar and Shweta (2011) investigated the feasibility of microbial pre-decomposition of timber wastes prior to vermicomposting to produce compost with higher agronomic value using *Drawida willsi* Michelsen. The timber waste was inoculated with different combinations of the fungi *Phanerochete chrysosporium*, *Trichoderma reesei*, *Aspergillus niger* and the bacteria *Azotobacter chroococcum* (MTCC 3853) and *Bacillus cereus* (MTCC 4079) and incubated at 28–30 °C in a mechanical composter. The inoculation enhanced the degradation of timber wastes, increased total nitrogen and improved the quality and enhanced production of vermicompost. Total nitrogen increased from 0.16% to 1.52% and total organic carbon decreased from 42% to 13%. Out of 10 microbial combinations tested for pre-decomposition, the combination of *P. chrysosporium + T. reesei* was found best in terms of ligno-cellulosic decomposition, and *P. chrysosporium + A. niger + B. cereus* with respect of cast output. The study showed that the microbial pre-decomposition of the wastes can significantly enhance agronomic value of vermicompost.

b) Amendment or mixing stage: Mixing of different types of organic waste materials is advisable prior to vermicomposting either to make the feed acceptable to worms or to get a good quality vermicompost (Gunadi et al., 2002). Several organic wastes such as paper-pulp mill sludge, sugar mill sludge, textile mill sludge, etc. have unsuitable properties for earthworms but these may be ideal feed if spiked with other suitable waste materials (Yadav and Garg, 2009). Table 1 encapsulates different organic amendments spiked with industrial wastes by various authors in yesteryears. The crop residues contain high cellulose contents and similar derivatives could be mixed with animal dung which has high nitrogen content to make a favourable feed for earthworms (Bansal and Kapoor, 2000; Frederickson et al., 2007). However, this stage can be ignored if the organic waste is favoured by the earthworms in its original form.

c) Vermicomposting stage: After pre-treatment, the organic wastes are fed to suitable earthworms' species. During this phase, earthworms enhance microbial activities in the wastes, decompose and condition them for the formation of vermicompost. During this stage optimum moisture and temperature should be maintained to have maximum worm activity.

d) Maturation Stage: The stabilization and maturation of vermicompost is done for few days. The vermicompost is ready to use once it is matured. The availability of nutrients to plants from organic manure is closely related to its maturity. Matured organic manure is well balanced in nutrients (N, P and K) with low C: N and C: P ratio, which indicates slow rate of nutrients release. While in case of unstabilized and fresh organic wastes, these rates are high and this condition may limit the microbial growth and ultimately retard or even stop decomposition and mineralization of wastes (Senesi, 1989). Mature vermicompost contains acceptable concentrations of phytotoxic compounds or short-chain organic acids (Brewer and Sullivan, 2003). The vermicompost maturity is considered as an important parameter for its quality assessment. Several indicators variables used for determining the maturity of vermicompost include: oxygen consumption and carbon dioxide production, drop in temperature, phytotoxicity assays, cation exchange capacity, organic matter nutrient content, C/N ratio, and humus content and quality.

Table 1. Organic amendments in some industrial wastes

S. No.	Industrial Waste	Organic amendment	Earthworm Species	References
1	Paper-pulp waste	Cattle manure	*Eisenia andrei*	Elvira et al. (1998)
2	Petrochemical sludge	*Mangifera indica* foliage, cow dung and saw dust	*Eudrilus eugeniae*	Banu et al. (2005)
3	Food industry sludge	Cow dung, Biogas plant slurry	*Eisenia fetida*	Yadav and Garg (2009), Yadav and Garg (2010)

Table 1. (Continued)

S. No.	Industrial Waste	Organic amendment	Earthworm Species	References
4	Solid textile mill sludge	Cow dung and poultry droppings, Biogas plant slurry	*Eisenia fetida*	Garg and Kaushik (2005), Garg et al. (2006)
5	Sugar mill filter cake	Horse dung	*Eisenia fetida*	Sangwan et al. (2008a)
6	Guar gum industry waste	Cow dung and saw dust	*Perionyx excavatus*	Suthar (2006)
7	Olive oil industry waste	Cattle manure	*Eisenia andrei*	Plaza et al. (2008)
8	Pressmud	Bagasse, sugarcane trash and cow dung	*Eudrilus eugeniae*	Sen and Chandra (2007)
9	Distillery sludge	Cow dung	*Eisenia fetida*	Suthar (2008)
10	Industrially produced woodchips	Sewage sludge	*Eisenia fetida*	Maboeta and Rensburg (2003a)
11	Dairy Sludge	Cereal Straw and wood shavings	*Eisenia andrei*	Nogales et al., 1999
12	Beverage industry waste	Cattle dung	*Eisenia fetida*	Singh et al., 2010
13	Sugar industry waste (bagasse)	Coir and cow dung	*Eisenia fetida*	Pramanik (2010)
14	Leather industry waste	Cow dung and agricultural residues	*Eisenia fetida*	Ravindran et al. (2008)
15	Sago industry solid waste	Cow dung and poultry manure	*Eisenia fetida*	Subramanian et al. (2010)

Table 2. Comparison of Traditional Composting and Vermicomposting processes

S. No.	Parameter	Composting	Vermicomposting
1.	Active agent	Microorganisms	Earthworms and microorganisms
2	Duration	6 – 9 months	2 -4 months including pre-composting
3	Products	Compost	Compost and earthworms
4	Odour	Foul	Earthy
5	Nutrient level	More than raw materials	Equal to or higher than compost
6	Temperature range	A therophilic stage is involved	No thermophilic stage
7	Aeration	Turning of waste is required	No turning required, it is achieved by earthworms

Source: Frederickson et al., (2007); Lazcano et al. (2008) and Somani (2008).

As compared to composting, vermicomposting results into two useful products, namely, the vermicompost and the earthworm biomass. The former can be used as a soil conditioner in agricultural crops and/or gardening and the earthworms can processed into proteins (earthworm meal) or used as feed in fish farms (Sabine, 1978; Fisher, 1988). The vermicompost is richer in available nutrient contents than compost (Zhenjun, 2004). A comparison of some parameters of composting and vermicomposting is presented in Table 2.

EARTHWORMS FOR VERMICOMPOSTING

The role of earthworms has been recognized since the end of the 19th century regarding the decomposition of organic matter and release of nutrients (Edwards, 2007). Greek philosopher Aristotle called earthworms ‘‘the intestines of the soil’. He believed that soil was an organic entity and the earthworms played an important role in maintaining the life of soil. Darwin called earthworms ‘‘ploughs of the earth’’ and his book entitled ‘‘The Formation of Vegetable Mould through the Action of Worms with observations on their Habits’’ published in 1881 renewed their importance. Darwin claimed that earthworms are one of the most important creatures in the ecosystem. In the 1950s, vermiculture was started in the United States for the production of fish baits.

The vermicomposting technology, using earthworms to produce valuable humus like materials and proteins for animal feed from organic matter, has been used successfully since 1970s and expanded rapidly in many countries such as England, France, the Netherlands, Germany, Italy, Spain, Poland, the United States, Cuba, Mexicao, China, Japan, Phillipines, India, New Zealand, Australia etc.

Different Earthworm Species In Vermicomposting: Different earthworm species exist on the earth in almost all regions except those with extreme climates. There are about 4,200 species of earthworms all over the world (Bhatnagar and Palta 1996). According to Julka et al. (2009), in India, there are about 590 species of earthworms with different ecological preferences. The earthworm species differ in their life cycles, behaviours and environmental requirements (Sharma et al. 2005). The distribution of earthworms is related to the physico-chemical characteristics of soils such as temperature, moisture, pH, carbon, nitrogen and C: N ratio etc. Most species of earthworms prefer soil with a temperature of 10–35^{o}C, moisture of 12–34%, pH of about 7 and C: N ratio 2–8 (Edwards and Lofty 1977; Kale and Krishnamoorthy 1981; Lee 1985). In general, the earthworms consume waste equivalent to its body weight varying from 0.5 to 0.6 g and produces cast equivalent to about 50% of the waste it consumes in a day. According to Bhatnagar and Palta (1996) earthworm population density of 1,20,000 adult worms/ha can consume 17.20 tones dung/ha/year. Similarly Satchell 1983 has reported that In a temperate deciduous forest, annual leaf fall of approximately three tones/ha/year can be consumed just in three months by the worms. These estimates sufficiently indicate that earthworms are important below ground biota mixing and incorporating organic matter. On the basis of morpho-ecology, the earthworms are classified into three categories (Bouche, 1977): a) *Epigeics b) Endogeic c) Anecic.* The earthworms of different ecological categories have different ability to decompose organic residues.

a) Epigeic earthworm: These earthworms do not make permanent burrows but they produce ephemeral burrows into the mineral soil for diapauses only. These exist above the mineral soil surface typically in the leaf litter, plant debris, decaying organic matter and feed on them. These species are mostly used in vermicomposting or organic wastes. Examples *Eisenia fetida* (Figure 2)*, Eisenia andrei, Eudrilus eugeniae* (Figure 2)*, Perionyx excavatus and Drawida modesta.*

b) Endogeic earthworm: These earthworms are burrowing worms and build continuous ramifying horizontal burrows. These worms inhabit mineral soil beneath the top soil surface and feed on soil more or less enriched with organic matter. These species are not very suitable for vermicomposting but play major role in soil formation processes such as soil mixing and aeration. Examples *Octochaetona thurstoni, Allolobophora caliginosa, Allolobophora rosea.*

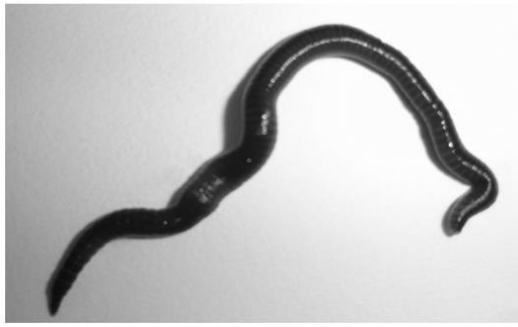

Figure 2. Adult Eisenia *fetida* worm.

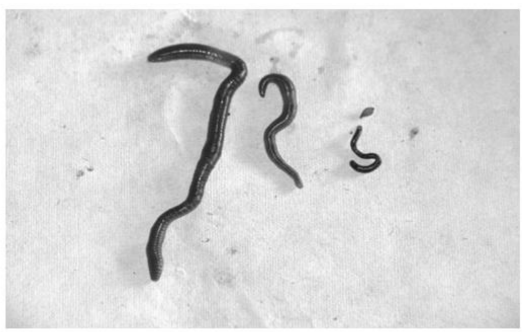

Figure 3. Adult *Eudrilus eugeniae* worm.

c) Anecic earthworm: These earthworms construct and live in permanent borrows in deep soil layers but come to the surface to feed on organic matter, mostly plant litter, and pull it into their burrow. These species have comparatively moderate reproduction rate and long life span. These species are very helpful in decomposition and distribution of organic matter in soil and also improve soil structure and texture by nutrient recycling. Examples *Lampito mauritti, Lumbricus terrestris and Octochaetona serrata.*

At maturity earthworms develops swollen region called clitellum behind the anterior. Worms deposits their eggs in a cocoon without the free larval stage. Cocoon production starts at the age of six weeks and continues till the end of six months. Under favourable conditions one pair of earthworms can produce 100 cocoons in six weeks to six months (Ismail 1997). Cocoon is a translucent, small, spherical protective capsule in which earthworms lay their eggs (Figure 4). The shape, size, colour and number of cocoons vary from species to species. The incubation period of a cocoon ranges between 03 and 30 weeks and in tropical worms within 1–8 weeks. Quality of organic waste is one of the factors determining the onset and rate of reproduction (Garg et al. 2007).

Suitable Species for Vermicomposting: The selection of suitable species for vermicomposting and consequential purpose/utilization is necessary. The earthworm species should possess a few characteristics, in order to attain the objectives of vermicomposting. These mainly include wide tolerance to environmental factors (varying temperature and moisture), adaptability for wide range of organic materials, high growth rate, low incubation period, high reproduction and cocoon production rate, high consumption, digestion and assimilation rate for organic matter decomposition and easy to culture.

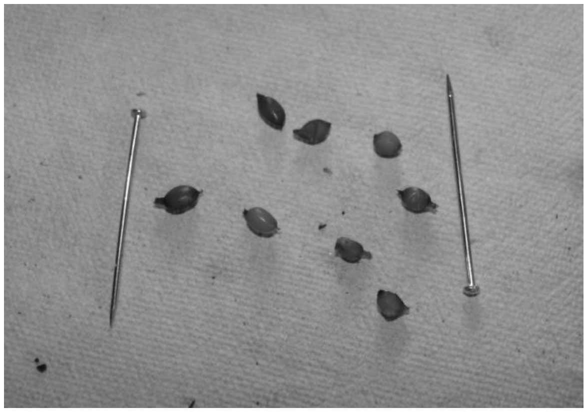

Figure 4. Cocoons of Eisenia *fetida*.

Table 3. Vermicultural characteristics of some earthworm species

Worm Species	Optimum temp. range (ºC)	Upper limit of temp. tolerance (ºC)	Age for cocoon production (weeks)	No. of hatchling Cocoons^{-1}	Incubation period (Weeks)	Wt (g)
Eisenia fetida	18 - 25	25	5-9	2-4	3-4	0.5
Eudrilus eugeniae	20 - 25	30	7-10	2-3	4	1
Perionyx excavatus	25 - 30	30	15-18	1	4	1
Lampito mauritii	18 - 30	30	8-10	1	4	1
Octochaeton a surensis	20 - 25	27	15-20	1	4	1
Drawida willsi	20 - 25	30	6-10	2-3	2	0.5

Source: Dash and Senapati (1985).

It is well established that epigeic species of earthworms are used widely for vermicomposting of organic wastes (Ismail, 2005). The commonly used epigeic species are E*udrilus eugeniae*, *Perionyx excavatus* and *Eisenia fetida* (Hartenstein et al., 1979). These species are prolific breeders, maintaining a high reproduction rate under favourable, moisture and food availability. They show high metabolic activity and hence are particularly useful for vermicomposting. The vermicultural characteristics of some earthworm species have been given in Table 3.

Neuhauser et al. (1988) investigated the reproductive potential of the five earthworm species viz., *Eudrilus eugeniae, Perionyx excavatus, Eisenia fetida, Drawida veneta* and *Perionyx hawayana* and suggested that *Eisenia fetida* is the most appropriate species for vermicomposting process. *Eisenia fetida*, commonly called Tiger or Brandling worm is ubiquitous and has the excellent properties in waste conversion and decomposition due to its wide applicability to the environmental conditions. It has high consumption, digestion and assimilation rate. It is found to assimilate 5- 10% of ingested matter and the rest is excreted as granular vermicast (Seenappa and Kale, 1995). Edwards and Bates (1992) have also reported that *Eisenia fetida* is the best choice due to its wide temperature and moisture tolerance, easy to handle and competes out other species. The highest growth rate in *Eisenia fetida* was found at 30^{o}C temperature and 85% moisture (Edwards and Bates, 1992).

VARIABLES THAT CONTROL THE VERMICOMPOSTING PROCESS

To optimize the vermicomposting process in order to achieve a good quality product, it is necessary to understand the variables that can control the efficiency of the process. Some of the process variables are described below:

1) Feed Quality: Suitable feed material for earthworms is of utmost important to have a successful vermicomposting system. Earthworms can feed on a wide variety of organic materials. But the feed should be free from non-biodegradable and toxic substance which may cause mortality of the worms. Worms are very sensitive to salts, preferring salt contents less than 0.5% in feed (Gunadi et al., 2002). Further, optimum C:N ratio in the feed is also required for efficient vermicomposting (Edwards and Lofty, 1972).

2) Temperature: Most earthworm species used in vermicomposting require moderate temperatures from 10–35^{o}C. The activity, metabolism, growth, respiration and reproduction of earthworms are greatly influenced by temperature (Riggle and Holmes, 1994). They should be protected from direct sunlight so that they do not dry up or overheat.

3) pH of the feed material: The earthworms operate efficiently in the pH range 5.5 to 8.5, however, a range of 7.5 to 8 is considered to be optimum (Edwards, 1998). The pH of the feed undergoes considerable changes during vermicomposting process. In the initial stages, formation of CO_2 and organic acids lower the pH values (Haimi and Hutha, 1986), and as the process progresses, the pH value rises due to subsequent evolution of CO_2 and utilization of volatile fatty acids (Kaushik and Garg, 2004)

4) Moisture: The ideal moisture range in vermicomposting process is 60-80% (Dominguez and Edwards, 1997; Edwards, 1998). The excessive moisture may cause anaerobic conditions in the bin, while lower moisture in feed may dry up the earthworms (Gajalakshmi and Abbasi, 2004a).

5) Aeration: As the earthworms are aerobic organisms, oxygen is essential for vermicomposting. Factors such as high levels of fatty/oily substances in the feedstock or excessive moisture combined with poor aeration may render anaerobic conditions in vermicomposting system. Worms suffer severe mortality partly because they are deprived of oxygen and partly because of toxic substances (e.g., ammonia) produced under such conditions. This is one of the main reasons for not including meat or other fatty/oily wastes in worm feedstock unless they have been pre-composted to break down the oils and fats.

Benefits of Vermicompost

The application of vermicompost has been shown to positively affect the structure, porosity, water holding capacity, nutrient contents, and organic matter content of the soil. Vermicompost contains most nutrients in plant available forms such as nitrates, phosphates, potassium etc.

The plant growth regulators and other plant growth influencing materials, viz., auxins, cytokinins, humic substances etc. produced by the microbes have also been found in vermicomposts (Atiyeh et al., 2002). The vermicasts possess high moisture content and aerobic conditions and hence provide an extraordinary favorable microenvironment for wide range of decomposing microorganisms (Lee, 1985).

Vermicompost is organic manure and has no potential harmful effects on plant growth and soil health. The addition of vermicompost to the soil can improve soil fertility by modifying its physical, chemical and biological properties such as bulk density, soil structure, water retention calacity, storage of plant nutrients, ion exchange capacity etc.

Vermicomposting of Different Solid Wastes

Non-toxic, organic and biodegradable organic wastes of any origin can be used as raw material for vermicomposting. A brief review of different waste materials tested for vermicomposting in recent years is given in the following sections:

A) Livestock Excreta

The livestock excreta/animal wastes are the potential source of plant nutrients. Recycling of animal wastes through vermicomposting reduces the problem of non-utilization of livestock excreta. Various animal manure such cow dung, horse dung, sheep manure, rabbit manure, goat manure etc. have been tested for vermicomposting. NPK content in the vermicompost prepared from different animal excreta has been given in given Table 4. A brief review of latest research on the vermicomposting of livestock excreta has been presented in this section.

A four months pilot-scale study was conducted by Song et al. (2014) to investigate the heavy metal and nutrient contents during composting of animal manure spiked with mushroom residues with and without earthworms. The accelerated organic matter mineralization (e.g., reduction in C/N ratio, increase in total concentrations of N, P, K) and humification (e.g., increase in humic acid concentration, humification ratio and humification index) were observed at the end. The study also reported the decrease in total heavy metal (i.e., As, Pb, Cu, and Zn) concentrations in vermicompost. The researchers suggested that vermicomposting process could not only magnify the nutrients but also reduce the heavy metals risk of agricultural organic wastes.

Table 4. NPK content in the vermicompost prepared from the excreta of different animals

S. No.	Vermicompost prepared from	N (%)	P (%)	K(%)
1	Cow dung	0.82± 0.05	0.43± 0.06	0.50± 0.04
2	Buffalo dung	0.78± 0.05	0.65± 0.06	0.58± 0.06
3	Horse dung	0.77± 0.03	0.38± 0.06	0.96± 0.04
4	Donkey dung	0.68± 0.03	0.73± 0.09	0.55± 0.03
5	Sheep dung	0.78± 0.02	0.45± 0.10	0.51± 0.03
6	Goat dung	0.89± 0.06	0.34± 0.09	0.47± 0.03
7	Camel dung	0.52± 0.03	0.36± 0.04	0.32± 0.03

Source: Garg et al. (2006).

Yadav and Garg (2014) studied the effect of poultry waste (PW) on the vermicomposting of anaerobically digested cattle dung slurry (CDS) using *Eisenia fetida*. Three vermicomposting beds were set with different ratios of PW and CDS (100% CDS; 75% CDS + 25% PW; 50% CDS + 50% PW). There was a decrease in pH, total organic carbon, carbon nitrogen ratio and carbon phosphorus ratio, but increase in calcium, sodium, total Kjeldhal nitrogen, total potassium and total phosphorus at the end. The results showed that PW addition to anaerobically digested CDS in vermicomposting enriched the vermicompost with nitrogen and phosphorus.

Wu et al. (2012) introduced an integrated crop-vermiculture system for treating organic waste on farmland using *Eisenia fetida*. They practised alternate bands of crop ridges and worm-farming troughs. The processing of cattle dung, sewage sludge, and mushroom residue in this system using a summer corn/winter wheat crop rotation system was done for three years. The results showed that this system is an effective method for processing waste, as well as for breeding earthworms. The crop-vermiculture system used no tillage or chemical fertilizer input as compared to conventional cultivation, and attained higher corn yield, improved soil porosity, and increased soil fertility. Although sewage sludge application had some cumulative effect on the heavy metal contents of soil, grain, and earthworms, short-term application was relatively safe.

Gomez-Brandon et al. (2013) evaluated the potential of *Eisenia fetida* to process large amounts of waste through continuous feeding reactors in which new layers of rabbit manure were added sequentially to form an age gradient inside the reactors. An optimal moisture level of 66 to 76% was maintained throughout the process using an automatic watering system. The pH decreased from 8.3 to 7.6 after 200 days of vermicomposting, while no changes in electrical conductivity through the profile of layers were observed. Based on comparisons of phospholipid fatty acid (PLFA) profiles and microbial activity measurements (basal respiration), a decrease in the levels of bacteria and fungi in layers occurred as the process progressed. The researchers considered it as a high degree of stabilization in the final product, which is of utmost importance for its safe use as an organic amendment.

Lv et al. (2013) described the characteristics and transformation of water extractable organic matter (WEOM) during vermicomposting of cattle dung using *Eisenia fetida* by chemical and spectroscopic methods. Results showed that the dissolved organic carbon was steady around 2.7 g/kg after day 60 and the dissolved organic carbon/dissolved organic nitrogen ratio decreased from 19.77 to 5.26 till the end of vermicomposting. On the other hand, vermicomposting decreased the aliphatic, proteinaceous, carbohydrates components and increased the aromaticity and oxygen-containing functional groups in the WEOM. Moreover, fluorescence spectra and fluorescence regional integration (FRI) results indicated that protein-like groups were degraded and fulvic and humic acid-like compounds were evolved during the vermicomposting process. In all, this study suggested the suitability of WEOM for monitoring the organics transformation and assessing the maturity in the vermicomposting.

Garg et al. (2005) have reported the growth and reproduction of *Eisenia fetida* in seven mammalian wastes (cow, buffalo, horse, donkey, sheep, goat and camel) during vermicomposting. The dung materials strongly influenced the biology of *Eisenia fetida.* The worm biomass gain in different animal excreta was in the order: sheep > donkey > buffalo > goat ≈ cow ≈ horse > camel. The number of cocoons produced per earthworm per day in different animal excreta was in the order: sheep > cow ≈ horse ≈ goat > camel > donkey > buffalo. The cocoons production was several folds higher in sheep waste than buffalo waste. They concluded that cow, horse, sheep and goat excreta are excellent raw material for large scale vermicomposting and vermiculture facilities.

Aira et al. (2006) studied the effect of C: N ratio of pig slurry on microbial biomass and growth & reproduction of the *Eisenia fetida* species of earthworm for 36 weeks. They reported that C: N ratio was significantly affected earthworm numbers (sevenfold greater in higher C: N ratio feed) and population structure. In low C: N ratio feed the worm population was mainly composed of mature earthworms (60%), with a higher mean weight than in the high C: N feed. However, in high C: N ratio feed, the population was mainly composed of juvenile and hatchling earthworms (70%). A rapid depletion in dissolved organic carbon content was observed in all the treatments. In another study, Aira and Dominguez (2007) reported the effect of application rate of manure on the microbial biomass & activity and carbon losses. For this, they designed continuous feeding reactors in which new layers of manure were added sequentially to form an age gradient inside the reactors. While comparing two application rates of pig slurry (1.5 and 3.0 kg), they found that earthworms increased microbial biomass and were more active in reactors fed with 3 kg of slurry. However, the differential rates of respiration were not reflected in carbon losses. They conclude that despite the strong effect that the rate of manure has on microbe–earthworm relationships, it did not affect carbon losses and recommended the use of low application rates of manure when the objective is the microbial stabilization of the residue.

Li et al. (2008) devised vermifiltration as a new technology to process organically polluted water. A pilot plant, associated with a swine facility (piggery) with 66 swine, was developed to treat diluted manure, produce earthworms & vermicompost, and reduce air pollution. The earthworm population was increased by 30% in 4 weeks, indicating the acclimation of the earthworms. A ≈50% reduction in ammonia emission was observed for the whole system. Higher water (+100%), carbon (+70%), and total nitrogen (+80%) gaseous losses were observed compared to conventional breeding on a slatted floor. This methodology can be used for further studies to develop vermifiltration of diluted animal manure without pollution transfer.

B) Farm Residues and Agricultural Waste

Farm residues and agricultural wastes are the potential source of plant nutrients and can be used as a substrate for earthworm feeding. Hanc and Chadimova (2014) carried out vermicomposting of apple pomace waste mixed with straw and the feasibility of the process was evaluated on the basis of agrochemical properties of vermicompost and earthworm biomass. The resulting vermicomposts were slightly acidic to neutral pH (5.9–6.9), optimal EC (1.6–4.4 mS/cm) and C: N ratios (13–14). The total nutrients content increased during vermicomposting for all of the treatments with the following average final values: N = 2.8%, P = 0.85%, K = 2.3% and Mg = 0.38%. Selven and Prabha (2014) studied the levels of macronutrients namely nitrogen, phosphorous and micronutrients namely Iron, copper in the leaf wastes during vermicomposting at different time intervals degraded by *Eudrilus eugeniae.* The level of both macro- and micronutrients in vermicompost was found to be significantly higher on the 25th day of vermicomposting.

Huang et al. (2014) investigated vermicomposting of fresh fruit and vegetable wastes (FVW) by contrasting two decomposing systems of FVW with and without earthworms for 5 weeks. Compared to control treatment (without earthworms), vermicomposting exhibited a rapid decrease in electrical conductivity and losses of total carbon and nitrogen from the 2nd week. Hayawin et al. (2014) conducted vermicomposting of empty fruit bunch (EFB) with palm oil mill effluent (POME sludge) using *Eisenia fetida* and *Eudrilus eugeniae*. Six vermibins with different fractions of EFB and POME sludge were established. The EFB was pre-composted using microbes before the vermicomposting process. Biomass gain and cocoon production of *E. fetida* and *E. eugeniae* were recorded weekly for 12 weeks. Maximum worm biomass and maximum cocoons were recorded for *E. fetida* in 70% EFB + 30% POME feed mixture. The results indicated that the addition of 30, 40, and 50% of POME sludge to the EFB is suitable for vermicomposting, suggesting that *E. fetida* may be a better choice than *E. eugeniae* for the rapid propagation of earthworms in oil palm wastes.

Shak et al. (2014) studied the transformation of rice residues alone and rice residues amended with cow dung (CD) using *Eudrilus eugeniae*. The final vermicomposts showed increases in macronutrients, namely, calcium (11.4-34.2%), magnesium (1.3-40.8%), phosphorus (1.2-57.3%), and potassium (1.1-345.6%) and a decrease in C/N ratio (26.8-80.0%) as well as increases in heavy metal content [iron (17-108%), copper (14-120%), and manganese (6-60%)] after 60 days of vermicomposting. Gomez et al. (2013) investigated the vermicomposting of tomato-plant waste (P) using paper-mill sludge (S) as complementary waste. Earthworm development in P, S, and two mixtures of both wastes was monitored for 24 weeks and compared with that in cow dung (D). The results showed that earthworms can not survive in P alone, but a mixture of P with S at a ratio of 2:1 or 1:1 supported the earthworm development equivalent to that observed in D. The efficiency of the process was assessed by analyzing the phospholipid fatty acid composition, chemical features, plant-nutrient content, metal concentration, enzyme activities, and germination index (GI). A commercial vermicompost was also analyzed and taken as a reference of vermicompost quality. Phospholipid fatty acid analysis revealed that earthworm activity strongly transformed initial microbiota inhabiting the wastes, giving rise to vermicompost microbial communities which were similar to that of a commercial vermicompost. Both mixtures of P and S were stabilized, as indicated by decreases in their C : N ratio and enzyme activities together with increases in their degree of maturity (GI ~ 100%) after the process. This study demonstrated that the vermicomposting of tomato-plant waste together with paper-mill sludge allows the recycling of both wastes.

Fornes et al. (2012) studied changes in physical and chemical characteristics of tomato crop waste throughout composting, vermicomposting using *Eisenia fetida* and integrating both the processes. Composting consisted of a combination of the static Rutgers system with forced aeration and pile turning. For combined process, pre-composted material was added to the worms. Particle size decreased during composting, yet it increased during vermicomposting and combined process due to the amalgamation of small particles. The pH was alkaline throughout the processes. A decrease in EC and greater leaching of organic matter, total nitrogen and most macronutrients in vermicomposting and combined process was observed than in composting. Final materials were not phytotoxic. Thus, thisstudy indicate that the products from the three processes could be good manures for horticultural purposes.

Vermicomposting of Java citronella (*Cymbopogon winterianus* Jowitt) waste biomass for recycling of distillation waste was carried out in two seasons, i.e., summer and winter periods using *Perionyx excavatus* by Deka et al. (2011). The experiment was conducted using a mixture of waste biomass and cow dung in the ratio of 5:1 with a control treatment without earthworms. The vermicompost had shown 5.8 folds reduction in C/N ratio and 5.6 folds enhancement in ash content. The nutrient contents (N, P, K, Ca and Mg) in the vermicompost were 1.2 – 4.1 fold higher than the initial level. The FT-IR spectra of the vermicompost confirmed increase in nitrogen rich compounds and decrease in aliphatic/aromatic compounds as compared to the initial level of the organic materials. The vermicomposting process was influenced by seasonal variation and summer was more productive than winter.

Lima et al. (2012) investigated the potential of converting Rice Husk (RH) amended with market refused fruit (market refused banana (B), honeydew (H) or papaya (P)) into vermicompost using *Eudrilus eugeniae.* RH was mixed with market refused fruit in an equal ratio to produce three different treatments (1B:1RH, 1H: 1RH and 1P: 1RH). The vermicomposting resulted an increase in potassium (15.0–121.4%), phosphorus (2.4–49.5%), and calcium (6.9–99.0%) after 9 weeks of vermicomposting. Among all the RH treatments, RH which was mixed with market refused papaya (1P:1RH) showed better quality vermicompost with higher nutritional status. It was also found that addition of papaya in RH encouraged the growth of earthworm as compared to the treatment with RH alone.

The post-harvest residues of some crops, e.g., wheat (*Triticum aestivum)*, millets (*Penniseum typhoides* and *Sorghum vulgare*), and a pulse (*Vigna radiata*) were utilized to recycle through vermicomposting by *Eudrilus eugeniae* (Suthar, 2008). Padmavathiamma et al. (2008) optimized vermicomposting conditions to convert biowaste (fresh banana leaves mixed with cow-dung in the ratio of 1:1 on a weight basis) to nutritious composts for amending agricultural soil. One ton of this biowaste was heaped on outdoor unpaved ground and exposed to the temperature between 29 and 32^{o}C for two weeks. The heat generated during the initial stages of decomposition, by the breakdown of complex biomolecules raised the temperature to >60^{o}C, i.e., to the thermophilic range. The worms were introduced after this stage Earthworm species *Eudrillus eugineae, Eisenia fetida*, *Perionyx sansibaricus, Pontoscolex corethrurus and Megascolex chinensis* were compared for their efficiencies in biodegrading organic wastes. *E. eugineae* was found to be a superb agent. As a bioinoculant, vermicompost increased nitrogen and phosphorous availability by enhancing biological nitrogen fixation and phosphorous solubilisation.

C) Household and Municipal Solid Waste

Management of household and municipal solid waste can be done at household level or at city level in a centralized manner. Lleó et al. (2013) have reported potential benefits of home composting and vermicomposting for the treatment of the organic fraction of municipal solid waste. Both the home composting and vermicomposting methods were studied over an eight-month period to determine the quality of the compost produced; the capacity of the methods and the resulting gaseous emissions. The vermibins had a treatment capacity of 50 g biowaste per L, whereas the home composter had a treatment capacity of 16 g biowaste per L. The home composter required the addition of 6.3 g of bulking agent per L of composter. The quality of the final product, compost, was similar in both cases, with each batch of compost having low metal content and a high degree of stability, with Dynamic Respiration Indices of 0.43 and 0.89 mg O_2 g^{-1} organic matter h^{-1} for compost and vermicompost, respectively. Gaseous emissions from home composters showed the presence of 1.3 kg NH_3 mg^{-1} biowaste and 1.35 kg CH_4 mg^{-1} biowaste, values that are within the range reported in the literature for home and industrial composting, although N_2O emissions, 1.16 kg mg^{-1} biowaste, were higher. Gaseous emissions from the vermicomposters were lower than from the home composters: 3.33×10^{-3}, 2.19×10^{-3} and 3.66×10^{-3} kg of pollutant mg^{-1} biowaste for NH_3, CH_4 and volatile organic compounds, respectively. No odours were detected for either system. The study concluded that home and vermicomposting can be considered suitable alternatives to divert a portion of the biowaste from the traditional waste-management system.

Tripathi and Bhardwaj (2004) conducted vermicomposting of kitchen waste amended with cow dung using *Eisenia fetida* and *Lampito mauritii* under tropical conditions. Both the species resulted in increased NPK and decreased C/N and C/P ratios after 150 days vermicomposting period. There was moderate mineralization and faster decomposition by *Eisenia fetida* in comparison to moderate mineralization and moderate decomposition by *Lampito mauritii*. The cocoons and hatcling production by *Eisenia fetida* was more than *Lampito mauritii*. Finally they concluded that *Eisenia fetida* may be a better adapted species for the decomposition of kitchen waste mixed with cow dung under tropical conditions. Nair et al. (2006) tested the combination of the thermocomposting and vermicomposting to improve the treatment efficiency and assess the optimum period required in each method to produce good quality compost. They concluded that thermocomposting prior to vermicomposting helped in waste stabilization, pH and moisture stabilization as well as for mass reduction. Vermicomposting after thermocomposting was effective in inactivating the pathogens. The study revealed that while treating kitchen waste, thermocomposting for 9 days followed by 2.5 months of vermicomposting produced pathogen free compost.

Pramanik et al. (2007) studied the effect of different organic wastes, viz. cow dung, grass, aquatic weeds and municipal solid waste with lime and microbial inoculants on chemical and biochemical properties of vermicompost. In the study, cow dung was found the best substrate for vermicomposting. They reported that application of lime (5 g/kg) and inoculation of microorganisms increased the nutrient content in vermicompost and also phosphatases and urease activities. *Bacillus polymyxa*, the free-living N-fixer, increased N-content of vermicompost significantly as compared to other inoculants.

D) Weeds

Large number of weeds that grow at an alarming rate and spread very fast in the cultivated lands, pastures, grasslands, forests and aquatic systems are also a good source of organic matter. The NPK levels in the vermicompost of weeds are given in Table 5. Various studies have revealed the decomposition of different weeds into vermicompost, thus eradicating the problems associated with them.

Table 5. NPK content in the vermicompost prepared from different weeds

S. No.	Vermicompost prepared from	N (g/kg)	P (g/kg)	K (g/kg)	Source
1	Lantana leaf + Cow dung (1: 4)	23.0	8.98	5.8	Suthar and Sharma (2013)
2	Water hyacinth + Cow dung (1 : 1)	18.0	8.1	6.8	Gupta et al. (2007)
3	Pathenium + cow dung (2 : 3)	13.0	4.0	14.0	Rajiv et al. (2013)
4	Azolla + cow dung (5 : 1)	12.3	0.65	40.3	Najar and Khan (2013)
5	Trapa + cow dung (5 : 1)	7.4	0.49	48.0	Najar and Khan (2013)
6	Ceratophyllum + cow dung (5 : 1)	6.4	0.57	52.3	Najar and Khan (2013)

Rajiv et al. (2013) reported the production of Parthenin toxin (sesquiterpene lactone) free vermicompost from *Parthenium hysterophorus* L. amended with cow dung using *Eudrilus eugeniae*. The 30–35% of organic carbon and 32–48% of phenol contents were reduced during the process after 45 days of earthworm's activity. FT-IR spectra revealed the absence of Parthenin toxin and phenols in vermicompost obtained at high concentration of cow dung. Earthworm's biomass gain was less in high concentrations of *P. hysterophorus* (without cow dung). The results indicated that Parthenin toxin and phenols can be eradicated via vermicomposting if *P. hysterophorus* is mixed with appropriate quantity of cow dung.

Water hyacinth (WH) (*Eichhornia crassipes)* is a noxious weed all over the world due to high growth rates. Several authors have reported the vermicomposting of WH using different species of earthworms (Sannigrahi et al. 2002; Gajalakshmi et al., 2002; Gupta et al., 2007). These researches have shown that vermicomposting is one among the promising alternatives for the management of this weed but the final product may have high concentrations of heavy metals due to higher heavy metals bioaccumulation potential of WH. However, the mobility and bioavailability of heavy metals and their related eco-toxicity to plants depend strongly on their specific chemical forms or ways of binding rather than total metal concentration (Singh and Kalamdhad, 2013a). Chemical speciation of heavy metals during composting is a useful technique for determining the chemical forms in which these metals are present (Hsu and Lo, 2001). Pare et al. (1999) have reported that water soluble and exchangeable fractions of metals are most available to the plants.

According to Tessier et al. (1979), heavy metals are associated with five fractions: (1) Exchangeable fraction: The exchangeable fraction is likely to be affected by changes in water ionic composition as well as sorption–desorption processes. They include weakly absorbed metals that are retained on the sediment/soil surface by relatively weak electrostatic attraction. (2) Carbonate fraction or acid extractable: This fraction is susceptible to changes in pH and at lower pH this fraction can be leached. (3) Reducible fraction: The reducible fraction is thermodynamically unstable under anoxic conditions. (4) Oxidizable fraction or fraction bound to organic matter: The organic bound fraction is released from organic matter under oxidizing conditions. (5) Residual fraction: The residual fraction in which metals are permanently bound in crystal lattice of the mineral components of the compost. Under natural conditions, residual fraction not enters the food chain, resulting it contributes very low or no bioavailability.

Singh and Kalamdhad (2013b) examined the speciation of heavy metals (Zn, Cu, Mn, Fe, Ni, Pb, Cd and Cr) during vermicomposting of WH with cattle manure and sawdust by using *Eisenia fetida* for 45 days in accordance with Tessier sequential extraction method. The pH was increased significantly during the process which was most important factor for reducing bioavailability of heavy metals. The exchangeable fraction of Mn and Zn was converted into less mobile fractions such as reducible, oxidizable and residual in the vermicompost. The residual fraction of Zn, Ni, Pb, Cd and Cr was dominant in all trials from initial to final compost. The exchangeable and carbonate fractions of Cu, Ni, and Cr were reduced in all trials. The Cu was mainly present in reducible and oxidizable fractions in the vermicompost. The Fe was mainly found in oxidizable fraction in all trials. The residual fraction of Ni, Pb and Cd contributed about 94–99% of total fraction. The exchangeable fraction of Cd was not found after 15th day of vermicomposting period. The reducible and oxidizable fractions of Ni, Cd and Pb were not found during the vermicomposting process. They concluded that *E. fetida* was incredibly effective for reduction of bioavailability of heavy metals during the vermicomposting of WH mixed with cattle manure and sawdust.

Suthar and Sharma (2013) attempted vermicomposting of *Lantana camara* leaf litter after spiking it with cow dung in different ratios using *Eisenia fetida* for 60 days. In all the five treatments, a decrease in pH (19.5—30.7%), total organic carbon (12—23%) and C:N ratio (25—35%), but increase in ash content (16—40%), total N (11—32%), available phosphorous (445—629%), exchangeable potassium (63—156%) exchangeable calcium (67—94%), and N-NO_3^- (164—99%) was observed. Vermibeds with 40—60% leaf litter showed better mineralization rates. The number of fungi, bacteria and actinomycetes showed 0.33-1.67-fold, 0.72-2.33-fold and 2.03-2.99-fold increase, respectively after vermicomposting process. Results suggested that Lantana may be a potential source for vermicompost production for sustainable agriculture.

Najar and Khan (2013) studied the potential of *Eisenia fetida* to recycle the different types of fresh water weeds (macrophytes) used as substrate in different reactors (*Azolla pinnata* reactor, *Trapa natans* reactor, *Ceratophyllum demersum* reactor, free-floating macrophytes mixture reactor, and submerged macrophytes mixture reactor) during 2 months experiment. *E. fetida* showed significant variation in number and weight among the reactors and during the different fortnights ($P < 0.05$) with maximum in *A. pinnata* reactor and minimum in submerged macrophytes mixture reactor. ANOVA showed significant variation in cocoon production ($F_4 = 15.67$, $P < 0.05$) and mean body weight ($F_4 = 13.49$, $P < 0.05$) among different reactors whereas growth rate ($F_3 = 23.62$, $P < 0.05$) and relative growth rate ($F_3 = 4.91$, $P < 0.05$) exhibited significant variation during different fortnights. Reactors showed increase in pH, EC, N, and K whereas decrease in OC and C/N ratio. Hierarchical cluster analysis grouped five substrates (weeds) into three clusters-poor vermicompost substrates, moderate vermicompost substrate, and excellent vermicompost substrate. Two principal components (PCs) have been identified by factor analysis with a cumulative variance of 90.43%. PC1 accounts for 47.17% of the total variance represents "reproduction factor" and PC2 explaining 43.26% variance representing "growth factor." Thus, the nature of macrophyte affects the growth and reproduction pattern of *E. fetida* among the different reactors, further the addition of *A. pinnata* in other macrophytes reactors can improve their recycling by *E. fetida*.

E) Sewage Sludge and Human Faeces

Sewage sludge is an unavoidable by-product of wastewater treatment processes. Its disposal is generally costly or contaminates the environment. Being rich in micro-and macronutrients, it can be a potential feedstock for earthworms in the process of vermicomposting. Yang et al. (2014) reported the vermicomposting of sewage sludge by *Eisenia fetida* and revealed the results by determining the water-extracts through chemical and spectroscopic methods. In a field experiment with sludge as the only feed for earthworms and the control (without worms) for three weeks they demonstrated that vermicomposting resulted in lower pH and water-extractable organic carbon along with higher electrical conductivity and nitrate. Fourier transform infrared spectra of vermicompost revealed that vermicomposting promoted the hydrolysis/transformation of macromolecular organic matters and accelerated the degradation of polysaccharide-like and protein-like materials in the process.

Kharrazi et al. (2014) reported an improvement in the quality of vermicompost through different substrates and adding active sewage sludge as a source of N-fixing and P-solublizing bacteria in a shorter time than conventional composting process. The experiment setup included 15-L reactors used for pre-composting, a vermicomposting mixture of activated sewage sludge (control, 2000, 4000 and 6000 mg/L) and corn stalk residue (40, 60 and 80%). After 70 days, the values of total organic carbon (TOC), total volatile solid (TVS), total Kjeldahl nitrogen (TKN) and carbon to nitrogen (C/N) ratio decreased in all treatments, while those of electrical conductivity (EC), total phosphorous (TP), nitrate and heavy metals increased. The vermicompost from a substrate with 80% corn waste showed the highest nutrient and the least heavy metal content. Increasing the concentration of sludge caused a decrease in the contents of TOC, TVS and in the C/N ratio and an increase in the content of TKN, nitrate, TP and EC. It was assumed that the integrated approach of employing microflora and earthworms together may be advantageous in converting waste quickly into a value added product

Molina et al. (2013) assessed changes in the chemical characteristics and biological parameters of *Eisenia fetida* using seven combinations of rabbit manure spiked with sewage sludge or vinasse waste. Sewage sludge vermicomposts had higher humus, nutrient and total metal contents, but lesser soluble salts than vinasse vermicomposts. The number and mass of worms were higher in rabbit manure, followed by sewage sludge, at decreasing doses. The researchers concluded that the total amount and composition of soluble salts in food may influence the quality of end products and are of primary importance for biological parameters of worms.

Nayak et al. (2013) conducted the vermicomposting of feedstocks prepared by mixing sewage sludge, cattle manure and saw dust in five different proportions (Rl, C/N 15; R2, C/N 20; R3, C/N 25; R4, C/N 30 and R5, control) based on C/N ratios employing *Eisenia fetida*.

The results showed that carbon content decreased and nitrogen content enhanced during the process. The C/N ratio decreased with time in all the reactors indicating a stabilization of the waste. It was observed that the trial R4 of C/N ratio 30 using sewage sludge along with cattle manure and saw dust produced the best compost, showed higher loss in Carbon, soluble BOD, soluble COD and higher gain in total nitrogen and phosphorus, implying the total amount of biodegradable organic material was stabilized.

The chemical changes of water-extractable organic matter (WEOM) from five different substrates of sewage sludge enriched with different proportions of cow dung were vermicomposted using *Eisenia fetida* (Xing et al., 2012). Results showed that dissolved organic carbon, COD, and C/N ratio of the substrates decreased significantly after vermicomposting process. The aromaticity of WEOM from the substrates enhanced, and the amount of volatile fatty acids declined markedly, especially for the cow dung substrate. Gel filtration chromatography analysis showed that the molecular weight fraction between 10^3 and 10^6 Da became the main part of WEOM in the final product. Fluorescence spectra indicated that vermicomposting caused the degradation of protein-like groups, and the formation of fulvic and humic acid-like compounds in the WEOM of the substrates. Overall results indicated that vermicomposting promoted the degradation and transformation of liable WEOM into biological stable substances in sewage sludge and cow dung alone, as well as in mixtures of both materials, and testing the WEOM might be an effective way to evaluate the biological maturity and chemical stability of vermicompost.

On-site sanitation solutions have gained much interest in recent years. Sanitation solution mainly includes the collection and treatment of human excreta to ensure the well-being of the individuals of a community. Commonly available on-site sanitation systems today are composting latrines and urine diverting dry toilets (Lalander et al., 2013). Buzie-Fru (2010) demonstrated the feasibility of using the vermicomposting technology as treatment of source separated faeces. He developed and tested a continuous single chamber vermicomposting toilet. He found that optimal conditions for vermicomposting of faeces was at a moisture content of 65–80% at 20–25^{o}C, achieving 50–80% reduction in organic carbon after 96 days of treatment. The main question with these solutions is whether the processed material, aside from being stabilized, also can be considered hygienically safe. Numerous reports demonstrate the capacity of vermicomposting systems to inactivate Enterobacteriaceae, such as Salmonella spp., Escherichia coli and Shigella spp. (Contreras-Ramos et al., 2005; Monroy et al., 2009; Kumar and Shweta, 2011). However, opinions differ whether vermicomposting has the ability to destroy or inactivate parasites such as the intestinal worm Ascaris spp. (Eastman et al., 2001; Bowman et al., 2006; Hill et al.,2013), while little is known about its effect on viruses.

Lalander et al. (2013) have investigated the hygienic quality of composted materials treated in six UDVTs (Urine diverting vermicomposting toilets containing mainly solid faeces and toilet papers) employing *Eisenia fetida* that had been in operation from two and five years in France. The concentrations of Salmonella spp., Enterococcus spp., thermotolarent coliforms and naturally occurring coliphages (used as indicator for animal viruses) as well as physico-chemical parameters were analysed. The study demonstrated that UDVTs systems are a viable option for on-site management of human waste as the vermicomposted material was odour free, homogenized. The accumulation of material in the toilets was kept down to a minimum, as the earthworms effectively reduced the material mass. As UDVTs do not require much maintenance, they are ideal for installation in remote locations.

Hill and Baldwin (2012) worked on the performances of composting toilets. They reported that source separating vermicomposting toilets (SSVCs) outperformed mixed latrine microbial composting toilets (MLMCs). MLMCs incurred ten times greater operational costs; created 10 times more operator exposure; employed no proven pathogen reduction mechanism. While SSVCs had low maintenance costs and risks, adequate worm density for pathogen destruction and reduced *E. coli* in neutral, stable, and mature end product.

F) Industrial Wastes

The potential of vermicomposting in stabilization of a variety of industrial wastes is well documented in published literature. A wide range of industrial sludges/wastes have been tested for their bioconversion into vermicomposts. Different authors have reported a significant NPK content in the vermicompost prepared from various industrial wastes (Table 6).

A 90 day study was conducted by Ponmani (2014) to evaluate the efficiency of *Eudrilus eugeniae* for decomposition of different types of organic substrates. Mixed liquor suspended solids (MLSS) of paper mill and leaf litter (LL) were mixed with cow dung (CD) in eight different ratios. All vermibeds showed a significant reduction in pH, organic carbon, C:N ratio and an increase in total nitrogen, phosphorus and potash. Maximize decomposition and mineralization efficiency was observed in bedding with lower proportions of MLSS. Maximum value for earth worm biomass and higher concentration of nutrient content was observed in CD + MLSS + LL in 1:1:2 ratios. Earthworm mortality tended to increase with increasing proportion of MLSS and maximum mortality in *E. eugeniae* was recorded for MLSS treatment alone. Results indicated that vermicomposting might be useful for managing the energy and nutrient of MLSS on a tow-input basis. Products of this process can be used for sustainable land restoration practices.

Table 6. NPK content in the vermicompost prepared from the sludge of different industries

S. No.	Vermicompost prepared from	N (g/kg)	P (g/kg)	K(g/kg)	Source
1	Pressmud + cow dung (1: 1)	33.6	28.8	20.4	Prakash and Karmegam, 2010
2	Paper mill sludge +cattle manure (1: 4)	12.0	5.9	7.6	Elvira et al., 1998
3	Solid textile mill sludge + cow dung (30% + 70%)	10.7	5.6	3.3	Kaushik and Garg, 2003
4	Beverage industry waste + cow dung (1 : 1)	15.9	6.5	17.6	Singh et al., 2010
5	Dairy sludge + cattle manure (1:4)	17	7.7	7.6	Elvira et al., 1997
6	Sago industry solid waste + cow dung + poultry manure (1:1:1)	19.4	15	25.6	Subramanian et al., 2010
7	Guar gum industrial waste + cow dung + saw dust (60:20:20)	24.8	4.35	18.7	Suthar, 2006

Goswami et al. (2013) converted tea factory and paper mill bottom ash (TFBA and PMBA, respectively) to organic manure through vermicomposting by *Eisenia fetida*, which would otherwise deteriorate soil and surface water quality through rapid acidification, releasing sulfur compounds and heavy metals. The wastes were mixed with farmyard manure in different proportions. Substantial increment in bioavailability of N, P, K, Fe, Mn and Zn along with remarkable decline in toxic metal like Cr due to vermicomposting was noteworthy. Further, vermicomposted mixtures of TFBA or PMBA with organic matter attributed profuse pod yield of French Bean (*Phaseolus vulgaris* L.). Goswami et al. (2014) studied the impact of metal rich Tea Factory Coal Ash on the reproduction, composting and metal accumulation ability of *Eisenia fetida* and *Lampito mauritii*. Earthworm count and cocoon production increased significantly during vermicomposting. The pH of the vermicomposted mixtures shifted towards neutral, total organic carbon decreased and total nitogen enhanced significantly. High heavy metal (Mn, Zn, Cu, As) accumulation was recorded in the intestine of both the earthworm species due to gradual increase in the metal-inducible metallothionein concentration. The study revealed that earthworms not only decomposed the organic materials into value added product but sequestered the heavy metals from the waste materials.

Sonowal et al. (2014) studied the potential of three different earthworm species *Eisenia fetida, Eudrilus eugeniae, Perionyx excavates* for the conversion of dewatered sludge (DS) of pulp and paper mill into stable compost. DS was mixed with saw dust (SD) in four different proportions such as (50:50, 60:40, 70:30 and 80:20). Stability of vermicompost was studied by analyzing C/N ratio, oxygen uptake rate, CO_2 evolution and biodegradable organic matter. Compost stability studies revealed that the final compost became stable in all proportions with every earthworm species. However the substrate combination of DS and SD (70:30) proved to be the best mixture on an overall basis with earthworm species *E. fetida.*

Kaushik et al. (2013) investigated the vermicomposting of dye laden biomass produced from adsorbent process for removing hazardous dyes from wastewater which poses disposal problems. In the study, the experiments were conducted on the Acid Navy Blue and Methylene Blue dyes which were biosorbed to the fungal biomass (strain closely related to *Aspergillus lentulus*) produced on corncob as the substrate. In order to dispose the dye laden biomass, it was vermicomposted along with cow dung (CD) employing *Eisenia fetida.* Results indicated that no mortality of earthworms was observed in dye laden biomass. But as compared with control experiments (where dye laden biomass was absent), the reproductive potential of the earthworms was affected. However, further investigations on optimization of biomass and CD ratios can facilitate vermicomposting as a potential route for disposing dye laden biomass.

Singh and Suthar (2012) studied the decomposition of the herbal pharmaceutical industrial waste (HPIW) mixed with cow dung (CD) in different ratios to produce five different waste mixtures for vermicomposting: T1 – CD (100%), T2 – HPIW (25%) + CD (75%), T3 – HPIW (50%) + CD (50%), T4 – HPIW (75%) + CD (25%) and T5 – HPIW (100%) using *Eisenia fetida* (Savigny) under laboratory conditions. A decrease in pH, organic C, C:P ratio and C:N ratio in all waste mixtures, but increase in total N, available P and exchangeable K was recorded. C:N ratio of vermicompost was within the agronomic preferable limit (>15). T3 and T4 vermibeds showed better mineralization and waste decomposition rate during vermicomposting. Results suggested that vermicomposting could be an efficient technology to convert HPIW into vermicompost for agronomic use.

Garg et al. (2012) reported the vermicomposting of food industry sludges (FIS) mixed with cow dung, biogas plant slurry and poultry droppings using *Eisenia fetida*. A total of 10 vermicomposting units containing different wastes combinations were established. After 15 weeks significant increase in total nitrogen (60–214%), total available phosphorous (35.8–69.6%), total sodium (39–95%), and total potassium (43.7–74.1%), while decrease in pH (8.45–19.7%), total organic carbon (28.4–36.1%) and C:N ratio (61.2–77.8%) was recorded. The results indicated that FIS may be converted into good quality manure by vermicomposting if spiked with other organic wastes in appropriate quantities.

Suthar et al. (2012) illustrated the vermistabilization of wastewater sludge from a milk processing industry (MPIS) unit spiked with cow dung (CD), sugarcane trash (ST) and wheat straw (WS) using *Eisenia fetida.* A total of nine experimental vermibeds were established for 90 days. Vermistabilization caused reduction in pH, organic carbon and C:N ratio and substantial increase in total N, available P and exchangeable K. The waste mixture containing MPIS (60%) + CD (10%) + ST (30%) and MPIS (60%) + CD (10%) +WS (30%) had better waste mineralization rate among all waste mixtures. The earthworm showed better biomass and cocoon numbers in all vermibeds during vermicomposting operation.

Bhattacharya et al. (2012) investigated various combinations of fly ash (FA) and organic matter (OM) like cow dung to interact with and without (control) *Eisenia fetida*. Vermicomposted FA when applied to a red and lateritic soil not only enhanced availability of three major nutrient elements viz. N, P and K but also helped to maintain low solubility of heavy metals like Pb, Cr and Cd in soil. Advantage of vermicomposted FA and organic matter (1:1) @ 10 t ha^{-1} in potato cultivation was evidenced by significant increase in crop yield due to enhanced soil fertility and reduced risk of heavy metal toxicity.

POTENTIAL APPLICATION OF VERMICOMPOST IN PLANT GROWTH

Soil organic matter plays a major role in maintaining soil quality. In addition to supplying plant nutrients, the type and amount of soil organic matter influences several soil properties. Thus, in the areas where organic matter content of soil is lesser, agricultural use of vermicompost is recommended for increasing soil organic matter. Apart from this, application of vermicompost can affect soil quality by: a) increasing soil microbial biomass and activity, b) improving tillage of soil, c) more vegetative growth of plants, and d) decreasing chemical fertilizers and pesticides requirement.

Vermicompost has been recommended as an ideal biofertilizer or manure for enhancing the growth and yield of crops and maintain soil health. The beneficial effect of vermicompost on plants may be due to their physical and chemical properties such as particle size, porosity, water holding capacity, air capacity, electrical conductivity and pH which are even more important than the concentration of nutrients (Gouin, 1998). The effect of vermicompost (VC) [prepared from an allelopathic weed lantana (*Lantana camara*)] on the germination, growth, and yield of cluster bean (*Cyamopsis tetragonoloba)* has been studied by Karthikeyan et al. (2014). In test plots, the soil was treated with the vermicomposts at the rates of 5, 7.5, and 10 t ha-1, and the plant growth was compared with the soil fortified with inorganic fertilizers (IFs) in equivalent quantities as well as soil only as control. The results indicated that 51.5% more germination success occurred in the VC treatments compared to controls. VC also supported better plant growth in terms of stem diameter, shoot length, shoot mass, number of leaves, leaf pigments and fruit yield. In addition, vermicompost application enhanced root nodule formation, reduced disease incidence, and allowed for a smaller number of stunted plants.

Belda et al. (2013) conducted the experiments to compare the suitability of one compost and vermicomposts (prepared from the same batch of tomato-crop waste) as growth media for two ornamental plants (*Calendula officinalis*, *Viola cornuta*) production. Each material was mixed with Sphagnum peat at 100: 0, 75: 25, 50: 50, 25: 75, and 0: 100 (peat control) proportions by volume. The plants were sown and grown in the 13 substrates. Substrates were characterized physically and chemically. The compost and the vermicomposts were markedly different from peat. Compost and the vermicomposts had greater bulk density and lower total porosity than peat. Compost had larger aeration and lower water-holding capacity than vermicomposts and peat. Compost was phytotoxic, as shown by the strong reduction of seed germination, chlorophyll content, and plant growth of both ornamentals. Vermicomposts did not affect seed germination but reduced plant growth, though significantly lesser than compost. Mixing these materials with peat improved germination and growth. The diluted materials (compost at the 25: 75 and vermicomposts at the 50: 50 and 25: 75 proportions) produced good quality plants.

Achsah and Lakshmi Prabha (2013) carried out vermicomposting of *Musa paradisiaca* (banana peel) waste using *Eudrilus eugeniae.* The enzymes (amylase, cellulase and invertase) and total macronutrients (N, P and K) and micronutrients (Fe and Cu) showed elevated levels in vermicompost than control (raw waste). The efficacy of vermicompost was studied on the vegetable plant *Solanum lycopersicum*. The growth parameters namely root length, shoot length and number of leaves was compared with the plants grown using chemical fertilizer (NPK). It was concluded that vermicompost obtained from the degradation of *Musa paradisiaca* (banana peel) waste by *Eudrilus eugeniae* was an effective biofertilizer which could facilitate the uptake of the nutrients by the plants resulting in higher growth and yield.

Atiyeh et al. (2000) have reported the differences in the effect of vermicompost and composts on marigold and tomato plants. Plants were less responsive to the composts than vermicomposts. This difference in growth may be due to the fundamental differences between the composting and vermicomposting processes which use quite different microbial communities, with composting tending to result in the release of mineral nitrogen in the ammonium form, whereas vermicomposting releases most of the nitrogen in the nitrate form (Edwards and Burrows, 1988), the form readily available for plant uptake. Kale et al. (1992) have reported an enhanced activity of the microbial populations (N-fixers, actinomycetes and spore formers) in a paddy field inoculated with vermicompost. There was higher level of total nitrogen in the experimental plots which may be due to the higher count of N-fixers. Garcia-Gomez et al. (2002) assayed the effect of two different vermicomposts prepared from brewing waste and olive mill waste on calendula and calceolaria plants and concluded that vermicompost so obtained was not phytotoxic and permitted the plants to grow disease free and with no weeds.

Arbuscular mycorrhizal fungi (AMF) are an important component of the soil microflora, promoting nutrient uptake into plants in exchange for carbon compounds from the host (Sylvia et al., 1998). Few studies have tested the effect of vermicomposts on AMF. Kale et al. (1987) reported an increase in AMF colonization in *Salvia* and *Aster* roots growing in a garden soil mixture amended with vermicompost. Cavender et al. (2003) have also reported an increase in AMF colonization of roots of *Sorghum bicolor* after vermicompost application. In contrast, Sainz et al. (1998) found that amending mineral soils with vermicompost of urban wastes caused significant reduction in AMF colonization of clover and cucumber roots, although growth was increased. These antagonistic effects of vermicompost on AMF colonization could be due to physical and chemical properties than biological effects (Cavender et al., 2003). Application of vermicompost to forest trees significantly improved their heights and diameters over those of control trees, although the increase were lower than those resulting from the chemical fertilizer application (Manna et al., 2003). Vermicomposting of Neem (*Azadiracta indica*) and its effect on growth and yield of Brinjal (*Solanum melongena*) has been reported by Gajalakshmi and Abbasi (2004b). They observed that the plants supplemented by the vermicompost had better height, root length and quicker onset of flowering and enhancement of fruit yield**.**

CONCLUSION

Vermicomposting produces a higher quality product, vermicompost, which has significant quantities of macro and micro-nutrients. Earthworms accelerate composting and produce an end-product which is more fragmented and has higher microbial activity. A large number of organic wastes can be used as raw material for vermicomposting provided these are bio-degradable and free from odour, toxins and salts. Other organic wastes, which are not preferred as feed by worms, can be made palatable after mixing them with cow dung, biogas plant slurry or other suitable bulking agents and pre-composting. However, a main disadvantage of vermicomposting is that temperature in the feed substrate must be maintained below 35^{o}C to avoid the mortality of the earthworms. The temperature during vermicomposting process is therefore not high enough for effective pathogen control. Earlier in 1980s vermicomposting research was limited to animal excreta, leaf litter, household waste and Municipality solid wastes management. But since 1990s vermicomposting research has shifted to sewage sludge and industrial sludges management. Some studies undertake integrated composting and vermicomposting has shown promising potential for the management of organic wastes. More research is required on the optimization of integrated system of composting and vermicomposting to have a sustainable and economically cheaper process. These areas certain other research areas, such as effect of biotic factor on vermicomposting process, use of local earthworm species in vermicomposting, value addition to vermicompost etc, in which research work is required.

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Chapter 9

SUSTAINABLE UTILIZATION OF OIL PALM WASTES: OPPORTUNITIES AND CHALLENGES

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ABSTRACT

Rapid increase in population has led to increased demand for food and shelter, putting immense pressure on various natural resources for their needs. As a result huge amounts of solid waste materials are produced and contribute to one of the major global challenges in the world today. Substantial increase in demand for oil in global markets has led to the rapid growth of the palm oil industry in countries like Indonesia and Malaysia. In Malaysia, palm oil mill waste contributes the highest fraction of total industrial solid wastes. Although there are many issues and challenges associated with the palm oil industry like environmental pollution, deforestation, biodiversity loss, and social conflicts etc., it also provides various opportunities such as increase in revenue and jobs. With this in mind, the current chapter was planned with the objective to discuss the issues, opportunities and challenges associated with the palm oil industry/oil palm waste in South East Asia with major emphasis on Malaysia.

Keywords: Oil palm, solid waste, empty fruit bunch, decanter cake, biodiesel

1. INTRODUCTION

The botanical name of oil palm is *Eleais guineesis Jacq*, which is derived from the Greek word elaion (oil) and guineesis, suggesting its origin (Equatorial Guinea). *Eleais guineesis*

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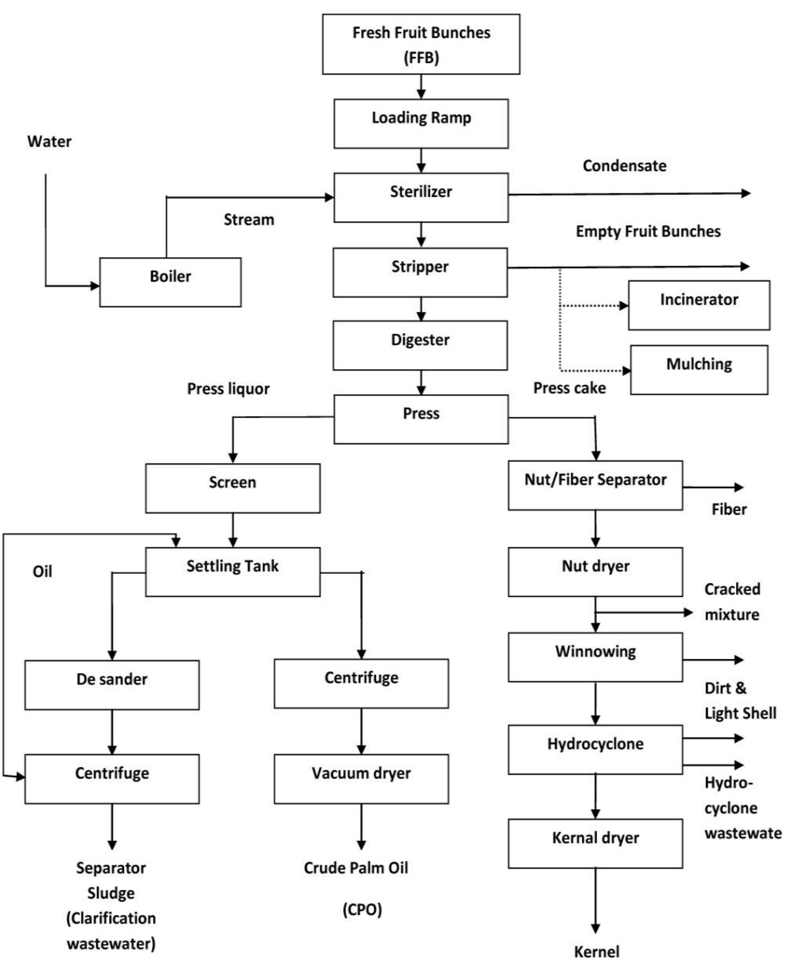
Jacq, is a monocotyledon, monoecious (both male and female flowers on the same plant) and tropical perennial plant belonging to the family Arecaceae (Palmea). *Eleais guineesis Jacq* is the most versatile species of palm which is used in large scale plantations. In the last few decades global demand for edible oils and fats has risen with the increased population and has resulted in a remarkable expansion in the area of oil crop cultivation mainly soybean and oil palm. In Malaysia, Oil palm plantation has increased from 2.03 million hectares (ha) to 4.49 million hectares from 1990 to 2009 (Embrandiri et al., 2012). Indonesia is the world's largest producer of palm oil (year 2006-2009), contributing about 44% of the total world supply, which is followed by Malaysia, with 43% of the total world supply of palm oil (Bazmi et al., 2011). In 2007, about 4.3 million ha lands were utilized for oil palm plantations in Malaysia and it is predicted that by the year 2030 annual production will be raised to 50 million tons (Ramachandra et al. 2004; Bazmi et al., 2011). It has been reported that over 89 million tonnes of fresh fruit bunch (FFB) is produced annually in Malaysia (Singh et al., 2010; 2011; Embrandiri et al., 2012). The palm oil industry plays a significant role in strengthening GDP of Malaysia as it contributes $ 7.3 billion annually through export (Embrandiri et al., 2012).



Source: Sethupathi (2004).

Figure 1. A schematic process flow of palm oil milling process.

Palm oil has broad applications from frying to margarine, snacks, instant noodles etc. It is also being used in cosmetics, soaps and synthetic detergents. Rise in crude oil worldwide made palm oil a much sought after fuel option. It could be regarded as the future of crops in view of its abundant uses. Fresh fruit bunches (FFB) are crushed to produce crude palm oil (CPO) along with other by-products. Oil palm is processed for two types of oils; the red palm oil from the fibrous mesocarp (40-50% of the FFB) and lauric oil/kernel oil obtained from the kernel (Dashiny, 2009). Kittikun et al. (2000) reported that kernel oil yield was about 40–50%. Corley (1983) reported that around 17 t ha^{-1} $year^{-1}$ of oil can be produced from both mesocarp and kernel of oil palm. According to Pleanjai et al. (2004), potential crude palm oil (CPO) yield of 5.8 tonnes of FFB is about 1 tonne. Fibre, shell, empty fruit bunch (EFB) and decanter cake accounts for 30, 6 and 28.5% of the FFB, respectively (Pleanjai et al., 2004). A schematic process flow of palm oil milling process has been illustrated in Figure 1.

With the increase in demand for palm oil in global markets, production rates have increased resulting in huge amounts of waste generated from the palm oil industry. Apart from that, globally increased demand for palm oil has resulted in rapid conversion from rainforest to oil palm plantation in South East Asia (Bazmi et al., 2011). The current practice of dumping in the most unscientific manner has led to excess nutrients in the soil. This is harmful to both the flora and fauna that live there. Oil losses due to process leakage result in increased oil concentration in the mill’s effluent. A total oil loss of 10 - 15 kg/t FFB has been reported (Chavalparit et al., 2006). In addition, inefficient equipment, defective machinery, leakage (by break down or overflow of tanks) may often be the reason for extra oil losses thus posing threat to the environment.

Despite the several applications of palm oil in recent times, the oil palm industry has drawn much negative attention among the scientific community because of many issues associated with oil palm cultivation like deforestation, biodiversity loss, peat land destruction and social conflicts. Likewise, palm oil industry also contributes to soil deterioration, water pollution and greenhouse gas (GHGs) emissions, posing threat to the environment. Thus, various strategies and policies are needed to be implemented to achieve the goal of sustainable management of palm oil industry in South East Asia.

2. Issues of Oil Palm Industry

2.1. Deforestation

Deforestation is usually defined as the conversion/clearing/removal of forest area/land for other purposes like agriculture, ranching, logging, urbanization etc. (Tan et al., 2009). Deforestation is caused either by anthropogenic factors or by natural factors (like natural fire, etc.). It has been stated by many scientists that one of the world’s oldest rainforests (located in islands of Borneo) has been cleared gradually for oil palm plantations. The clearing of tropical forests for oil palm plantation poses several negative effects on stability of ecology (WWF, 2005).

This leads to destruction of habitats of many endemic as well as endangered animals e.g., Sumatran rhinoceros, Asian elephants and tigers (Tan et al., 2009).

Apart from that, use of fire for land clearing greatly contributes to GHGs emissions. A report by WWF (2007) indicated that the total forest decrease in Kalimantan was about 13.3 million ha from 1985 to 2002, whereas in Sabah and Sarawak (Malaysia), the forest decrease was estimated to be 0.25 and 0.40 million ha respectively. This is mainly due to the oil palm plantation.

2.2. Biodiversity Loss

Biodiversity loss is directly related to destruction of natural forests. Due to the poor structural complexity in oil palm plantations, species' richness (biodiversity) is much lower in comparison to the natural forests (Teoh, 2010). Conversion of natural forests for oil palm plantations leads to animal-human conflicts e.g., elephant-human conflict has been reported along the flood plains of Kinabatangan River in Sabah (Malaysia), where the natural passage of the pygmy elephant has been fragmented due to the oil palm plantations. One of the world's oldest rainforests, Borneo (including three countries viz. Brunei, Indonesia and Malaysia) island, is also one of the mega-biodiversity centres (Myers et al., 2000). Malaysia has one of the world's richest flora and fauna consisting of about 15,000 plant species (MNS, 2011). The destruction of tropical forests in Asia for oil palm plantation greatly threatened the biota of this region. For instance, critically endangered Sumatran orangutans (*Pongo abelii*) and endangered Bornean orangutans (*Pongo pygmaeus*) are facing extinction due to expansion of various agricultural activities and oil palm plantation is one of them (Tan et al., 2009). Similarly, Sumatran rhinoceros (*Dicerorhinus sumatrensis*), sun bears (*Ursus malayanus*), tigers (*Panthera tigris*), clouded leopards (*Neofelis nebulosa*) and Indian elephants (*Elphas maximus indicus*) are greatly threatened by oil palm expansion in peninsular Malaysia (Gardenfors, 2011). Koh and Wilcove (2008) reported a significant decrease of 83% in butterfly species richness as well as a decrease of 77% in bird species richness due to oil palm plantations as compared to the natural forest in peninsular Malaysia. The fertilizers, herbicides and pesticides that is required for oil palm plantation enters into adjacent water bodies as runoff posing adverse effect on aquatic biodiversity (Fitzherbert et al., 2008; Butler and Laurance, 2009).

2.3. Peatland Destruction

Peatland is a wetland which contains a high fraction of incomplete decomposed organic matter made up of dead and decaying plant material (Tan et al., 2009). In peatlands, decomposition of dead organic material slows down due to water logged condition, where the oxygen deficient condition inhibits or slows down microbial activity (http://www.peatlandsni.gov.uk/formation/index.htm, 2007). Peatlands cover nearly 3% of the earth's land area and can act as a major carbon sink which can store large amounts of carbon resources, approximately 528,000 megatonnes, which is equivalent to one-third of global soil carbon (Hooijer et al., 2006). Thus, it helps in maintaining global carbon cycle in the atmosphere. In South East Asia, peatlands cover 27.1 million ha of the total land area which accounts of 6% of the total peatlands of the world (Hooijer et al., 2006). In Indonesia, the peatlands cover 22.5 million ha of the total land area. In Malaysia, peatlands cover 20,000 to 25,000 km^2.

About 9,000 km^2 of this area is located in Peninsular Malaysia whereas pristine peatland accounts for 500 km^2 (ASEAN, 2009). Due to the increase in demand of palm oil in global market, the rate of conversion of peatlands for oil palm plantation is accelerated which has detrimental effects on the environment. It is estimated that in Indonesia and Malaysia about 25% of the total oil palm plantation is done on peatlands (Silvius, 2006). Page et al. (2009) predicted that there will be increase in conversion of an additional 60,000 km^2 peatlands over the next 20 years. Peatland fire significantly contributes to GHG emission especially CO_2 in South East Asia and it is estimated that due to peatland drainage this amount will be doubled as peat is exposed to oxidation resulting in significant release of CO_2 (Silvius, 2006).

2.4. Social Conflicts

Land conflicts are a major issue of oil palm plantations. Generally conflict occurs between smallholders, local communities, indigenous people and palm oil companies as well as with the government. Oil palm plantation is usually associated with negative social impacts on local people and rural communities (Marti, 2008; Sirait, 2009; FoE, 2010). Marti (2008) reported that a number of cases of human right violation were filed on oil palm plantation companies by indigenous people particularly during land acquisition and plantation development. About 150 litigation cases on land disputes involved local people; 40 cases related to palm oil have been reported in Malaysia (Teoh, 2007). Similarly, 630 land disputes between oil companies and local people were reported in Indonesia in the year 2010 (Colchester, 2010; Obidzniski, 2012).

Orth (2007) reported that oil palm plantation had adversely affected the shifting cultivation of local Dayak communities in Central Kalimatan, leading to food insecurity. Apart from that, health problems have been reported among female workers which are involved in field operations like planting, weeding or pesticide application. For instance, it has been reported that paraquat application is responsible for health issues among female workers and the risk is aggravated during early stage of pregnancy (Obidzniski, 2012).

3. Sustainable Utilization of Palm Oil Mill Wastes (POMW): Its Potential Benefits/Opportunities

3.1. Agricultural Uses of Palm Oil Waste

3.1.1. Empty Fruit Bunch (EFB)

Empty fruit bunches (EFB) are mostly returned back to the plantations. Some of the recycling options which exist include: a) direct application of EFB on land. b) Hamadan et al. (1998) reported that it was mainly used as mulch, which helped to control weed; prevent erosion and maintain the soil moisture. The rate of absorption depends on the type of soil and the humidity conditions of the location. This is suitable for dryer inland plantations. c) Application as organic fertilizer. EFB contains cellulose (45-50%), hemicellulose and lignin in same proportion (Deraman, 1993) which is a good substrate for the growth of microbes.

3.1.2. Palm Press Fiber (PPF)

FFB contains 15% of Palm fibers which are commonly used as fuel for running boilers (calorific value of dried fibers <5 MJ/kg). Apart from that it can also be used as a blend with animal feed and act as a substrate for enzymatic saccharification. Huge amount of palm fibre (more than 40%) could reduce feed's digestibility whereas addition of 5 to 6% NaOH (w/w) or urea followed by 15-20 days fermentation can improve its quality. Besides this, it also helps in promoting vegetative growth and foliar nutrient level (Yusoff, 2004). Palm Press Fibre (PPF) ash contains 1.7- 6.6% P, 17- 25% K, 7% Ca which indicate that PPF is a good source of minerals to plants.

3.1.3. Palm Kernel Cake (PKC)

Palm kernel cake (PKC), is also referred to as palm kernel expeller (PKE) is of a grayish white colour. It is an outcome of a mechanical extraction process to produce kernel oil. It is said to be rich in carbohydrate (48%) and protein (19%) and suitable as feedstock (Kolade et al., 2005). An amendment of PKC and goat manure or poultry droppings could be a good organic fertilizer (Saw et al., 2008).

3.1.4. Palm Oil Mill Effluent (POME)

Palm Oil Mill Effluents is usually derived through oil extraction, washing and cleaning process in the mills, thus contains fats, oil and grease. POME is regarded as one of the major source of environmental pollution in palm oil producing countries (Schuchardt, 2008).

In extraction of each tonne of palm oil around 3 tonne of POME is generated and in 2010, 49.85 million tonnes of POME was produced (GGS, 2011).

POME contains high proportion of carotene, which acts as an antioxidant protecting the cells against free radicals (Abdullah, 2008). Due to several medicinal values of carotene like anti-cancer properties, immunity booster, g blindness and skin disorders preventer, pharmaceutical industries are keen on the extraction of carotene from the palm oil mill effluent. The pollution potential of the effluent is also reduced when oil and grease is removed.

3.1.5. Decanter Cake (DC)

Decanter cake /Palm oil sludge is a by-product obtained in the extraction phase of processing for palm oil (Seephueak et al., 2011). About 160-200 tonnes of DC can be produced in a mill with 90 t hr^{-1} FFB processing capacity (Haron and Mohammed, 2008) It is distinguished by considerable inconsistency in chemical composition i.e., high fat, high mineral and medium crude protein contents. At present, majority of the decanter cake produced is used as fertilizer and soil cover materials in the plantation area or as biogas production (Chavalparit et al., 2006; Paepatung et al., 2009); however its utilization in animal feed is minimal due to its acidic nature. Bamikole and Babayemi (2008) reported that the sludge has good potential as food source and could be directly used in ruminant feeding as an energy source in combination with nutrient supplements.

Application of DC together with inorganic fertilizer show synergic effect and enhance crops nutrient uptake and also enhance the nutrient retention in the soil for the long term to improve soil quality (Haron and Mohammed, 2008). They tested the combination of DC and inorganic fertilizers on palm seedlings and found that there were growth improvements as compared to control plants.

3.1.6. Microbial Applications

Empty fruit bunch were used as test samples to observe their potential in enhancing bioremediation of soil contaminated with tapis crude oil. Hamzah et al. (2014) carried out an experiment in which oil palm empty fruit bunch (20%, w/w) were mixed with soil (500g) spiked with Tapis crude oil (3%, v/w). After 20 days of treatment with EFB, the growth of bacteria consortium had increased to 9.5 CFU/g (*Pseudomonas aeruginosa* UKMP-14T and *Acinetobacter baumannii* UKMP-12T). Refined palm oil can be used as an alternative carbon substrate to oleic acid for microbial lipase production.

Another way to minimize the waste from the industries is composting technology. Composting is a microbial practice which is used in stabilization of organic wastes either from industrial or domestic origin. During the composting process, aerobic microorganisms decompose the substrate under controlled conditions like pH, temperature and humidity. Most of the biodegradable organic materials are broken down here by microbes to produce stabilized end product known as compost which is rich in humic acid-like substances (Epstein, 1997; Ipek et al., 2002). Composting reduces the weight/volume of the wastes (Rahman et al., 2003). In order to improve the composting process, we need to increase the degradation rate and quality of final compost. Several modifications have been tried such as addition of biodegradable waste to reach the optimum C/N ratio of about 30 (Costa et al., 1992). This is commonly known as co-composting (Baharaddin, 2009). Yaser et al.(2007) carried out the co-composting process by using the palm oil mill sludge (POMS) with saw dust. The mixture of POMS and saw dust will prevent air pollution and increase the efficacy of composting process (Pandey, 1996).

The earthworms can be introduced during composting to get a good quality organic fertilizer, this is known as vermicomposting. During vermicomposting earthworms together with microorganisms convert organic waste materials into a stabilized humus-like material known as vermicompost or earthworm compost. Through the vermicomposting process, physical, chemical and biological reactions take place, resulting changes in the organic matter. The resultant product (vermicast) is much more fragmented, nutrient rich, porous and microbially active (Edwards 1988; Edwards and Bohlen, 1996). Moreover the earthworm can further be processed as a source of animal feed (Hartenstein and Hartenstein, 1981; Sabine, 1978). During the vermicomposting process important plant nutrients like nitrogen, phosphorus, potassium etc. present in the organic waste material are converted into many soluble and available forms to plants (Longsdon, 1994). As a result it increases the plant nutrients as compared to the simple composting (Nagavallemma, 2004).

Several researches clearly suggested that earthworms could be utilized for stabilizing biodegradable portion of municipal solid waste as well as industrial waste (Ghosh et al., 1999). In this regard vermicomposting is considered as a promising, viable, cost effective technique for the efficient management of the organic solid waste (Longsdon, 1994; Hand et al., 1988). As high nutrient demand is required during oil palm plantation, therefore using palm oil mill waste as fertilizer supplement in place of inorganic nutrients is an eco-friendly, cost effective and more sustainable option. Sabrina et al. (2009) carried out a study on the vermicomposting of oil palm empty fruit bunches (EFB) and its potential in supplying of nutrients for crop growth found positive results.

3.2. Non-Agricultural Use of Oil Palm Biomass

3.2.1. Empty Fruit Bunch (EFB)

Malaysian Palm Oil Board (MPOB) had carried out a study to convert EFB into paper-making pulp. Chlorine-free methods were also used for bleaching the pulp for paper production (Gurmit et al., 1999). They were used for making cigarette paper and bond paper. (Malaysian National News Agency, 2001).

Small Renewable Energy Power Program (SREP), an initiative of the Malaysian government commenced in 2001 with the aim of utilizing clean and renewable fuel sources for generating electricity (Idris, 2003). EFB was used as the fuel source. The other objective of SREP included reducing the dependency on oil as well as reducing greenhouse gasses emission (Molktar, 2002). At the end of 2011, 40 MW of renewable capacity generated from EFB was connected to the national grid (Sovacool and Drupady, 2011). However, this project was suspended afterwards.

Another program run by a Japanese company (Chubu Electric Power) was announced in 2006 (Japan's Corporate News). Two small scale biomass power plants were built to generate 10MW from renewable energy resources (EFB). One of the power plants had begun its operations in 2008. This project was registered as a CDM (Clean Development Mechanism) project with United Nations (UN) (Chubu Electric Power, 2014).

Also as one of the major edible oil refiner and exporter in the country, PGEO Group Sdn. Bhd, in 2005 constructed a biomass-fired steam generator plant located in Lumut, Perak. The project was aimed to reduce the steam production from fuel oil and grid generated power and consequently reducing the emission of greenhouse gases by replacing fuel oil with oil palm biomass; replacing electricity from the national grid by changing the existing chiller system and to generate electricity from biomass. The fuel sources for operating this plant are oil palm EFB, PKS and mesocarp fibers from neighboring palm oil mills (Ministry of Foreign Affairs of Denmark, 2006; CDM, 2005).

3.2.2. Palm Fiber and Shell

Combustion of palm fiber and shell as boiler fuel generated oil palm ash (OPA) as a byproduct that can be used as absorbent to remove pollutant gases. High amounts of calcium, silica, potassium and alumina were observed in OPA which contributed to synthesizing of active compound for absorbing pollutant gases (Zainudin et al., 2005). Ying et al. (2014) reported EFB and kenaf core fibers treated with water, acid and alkaline mediums enhanced the hydrolysability. Hence the conversion of sugar from cellulose was improved and was crucial for increased production of cellulosic ethanol.

Mazaheri et al. (2010) had used oil palm fruit press fiber to produce bio-oil through subcritical water treatment and efficiency of different catalyst was also studied.

3.2.3. Fronds

Fronds that had undergone chemical pulping process showed excellent strength that was comparable to hardwoods. The data suggested the potential of fronds being utilized as reinforcement component in newsprint production using softwood thermo-mechanical fibers (Wan Rosli et al., 2007).

3.2.4. Trunk

Particle board is in growing demand worldwide and most of the commercial particle boards are bonded with formaldehyde-based adhesives which in terms of sustainability is not a good option. Formaldehyde standards for composite wood product act were signed into US law in 2010 (Jang et al., 2011) Hence, the need of finding formaldehyde-free adhesive is imminent. Concerns of decreasing wood supply, forestry regulations and the sustainable use of forest resources have advocated intense research in obtaining alternatives for other lignocellulosic material for manufacturing of composite panels (Saari et al., 2014). Malaysia, as one of the largest palm oil producing country, has massive potential venturing into particle board production as most of the byproducts from palm oil processing such as trunk are not effectively utilized. Various studies have been carried out on other lignocellulosic materials such as kenaf (Okuda et al., 2006), sugar cane and sorghum stalks (Shen, 1986), wheat straw (Halvarson et al.,2009), coconut husk (Jan et al., 2004) and banana bunch (German et al., 2009) and oil palm frond (Laemsak et al., 2000) in manufacturing binderless board. However, Sulaiman et al. (2009) considered oil palm as a high potential, non-wood lignocellulosic materials in producing wood based panels. Binderless particle board produced from oil palm trunk was reported to have high mechanical strength. In recent studies, both young and old palm trunk were used in producing binderless particle board. However, binderless panel made from young trunk showed superiority in terms of mechanical and physical properties (Lamaming et al., 2014).

3.2.5. Palm Oil Fuel Ash (POFA)

Palm Oil Fuel Ash **(**POFA) is a byproduct of the palm oil industry produced when the solid wastes of the mill are used as fuel to generate electricity. It is an agricultural solid waste that is being produced abundantly in Malaysia and Thailand. Utilization of POFA as a source of siliceous material for the synthesis of adsorbent for flue gas desulfurization is now being studied (Schuchardt, 2008). It is very unmanageable due to its minute particles and most times it is disposed of in landfills resulting environmental and health hazards. The other agricultural waste ashes have been used in concrete making, but POFA, a silica rich waste having good potential to be used as cement replacement is yet to be utilized as such (Tangchirapat et al., 2007). However more research has to be conducted to prove its efficiency. This would in the long run reduce environmental problems and render the landfill sites safe. Table 1 summarizes both the agricultural and non-agricultural uses of palm oil mill wastes. Tables 2 and 3 reports biomass production from the various in Malaysia and calorific value of oil palm biomass and estimated energy generated.

Table 1. Summary of both the agricultural and non-agricultural uses of palm oil mill wastes

No.	Type of palm waste residue	Uses
1	Fronds, trunks and leaves	Used as mulching material in the fields which helps in moisture retention. Also used as roofing material and some are processed as furniture.
2	Empty fruit bunch(EFB)	Generating steam for the mills and ash residues used as fertilizer.(Lim, 2000) As raw material for products such as paneling, composites, fine chemicals, pulp and paper as well as compost and bio-fertilizer [Ramli et al., 2002] Main substrate for the cultivation of *Pleurotus ostreatus* (oyster mushroom) (Tabi et al., 2008)

Table 1. (Continued)

No.	Type of palm waste residue	Uses
3	Palm press fibre (PPF)	Was previously used for fuel for the mills(Astimar et al., 2002) Used as a substrate for animal feed in addition to soymeal, fishmeal. Used as potting material for ornamental plants to improve foliar growth(Yusoff, 2004) Used for making fibre boards.(Ramli et al., 2002) Polymeric composites for building materials referred to as AGROLUMBER for products like wall panels, sub-floors, doors and furniture parts. (MPOB, 2009)
4	Decanter cake (DC)	Used as animal feed (Southworth, 1985) Used in combination with inorganic fertilizer to improve soil quality on palm plantations (Haron and Mohammed, 2008) Utilization of oil palm decanter cake for cellulase and polyoses production (Abdul Razak et al.,2012)
5	Palm kernel cake (PKC)	Suitable as feedstock because it has 48% carbohydrate and 19% protein (Kolade et al., 2005).
6	Palm kernel shells (PKS)	Used mainly for fuel. (Paepatung et al., 2006) Converted into activated carbon for water purification purposes(Ortiz et al., 1992)
7	Palm oil mill effluent (POME)	Mainly used for Irrigation purposes but due to its acidic nature is quite toxic to flora and hence needs to be treated. Carotenes are extracted from POME by pharmaceutical industries(Wood and Lim., 1989)

Table 2. Biomass production of various industries in Malaysia (Hassan and Shirai, 2003) (Modified from Shuit et al., 2009)

Industry	Biomass production (%)
Oil palm	85.5
Municipal solid waste	9.5
Wood industry	3.7
Rice	0.7
Sugarcane	0.5

Table 3. Calorific value and energy potential of oil palm biomass by component (Modified from Shuit et al., 2009)

Biomass component	Calorific value (kJ/kg) (Sumathi et al., 2008)	Potential energy generated (Mtoe)
Empty fruit brunches (EFB)	18,838	7.65
Fiber	19,068	4.37
Shell	20,108	2.84
Palm Kernel	18,900	0.95

4. Challenges

Utilization of oil palm biomass in industries, agriculture and biofuel production faces lots of challenges. Various researches have provided positive feedback and findings with regard to sustainable use of palm wastes. However, there is a big gap between these findings and the industries. Industries that have the intention of fully utilizing these wastes are gravely challenged by the production cost. For example, biodegradable plastic in United States is about 5 times higher compared to common thermoplastics (Hassan et al., 2014). Therefore, risk of profitability is too high and will be a major concern for any industry that supports or participates in the program.

Awareness of the potential of this biomass derived byproduct as source of renewable energy is low. Vital and practical information has not reached the targeted group and this has explained the limited success of previous awareness campaign. A survey revealed that 58% of the participants in the renewable energy program are unclear of its benefit (Umar et al., 2014).

The idea of connecting biomass facilities to energy grid also faces challenges. The burning of EFB to produce electricity or heat was introduced. However due to environmental concerns, the government of Malaysia banned it. Hence, it is also a challenge to promote oil palm biomass as renewable energy source. Currently, only 1% of the biodiesel produced in Malaysia is allocated for local consumption and is limited to test vehicles. Biodiesel usage in private sector and public is extremely limited (Lim and Lee, 2012).

Many industries still run on the conventional method which is relying on fossil fuel. For these industries to switch to more eco-friendly biofuels they will need more enlightenment and enforcement by the governments. Utilization of oil palm biomass in the various industries is yet to be fully explored and it is the responsibility of research institutes and universities to reach out.

CONCLUSION

Oil palm is an economically valuable crop which helps in improving the GDP of South East Asian countries. Although palm oil has several uses, in recent years the palm oil industry has drawn much negative attention because of several environmental and social issues associated with it. Increasing demand of palm oil in the global market has led to the rise in plantations in South East Asian regions. This in turn results in the destruction of existing forest. Clearing of land adversely affects the biodiversity of this region. Apart from that effluent, the palm oil industry is also responsible for air and water pollution. Although there are various issues associated with oil palm industry/oil palm waste, it also provides several opportunities in terms of products obtained from it. Likewise, it is also a good source of renewable energy, which is essential for development of any nation. Thus, if palm oil mill waste is managed in an appropriate manner it will not only help in mitigating its negative impact but also will help in improving the economic status of the country. Therefore, a good strategy and policy is needed to be implemented to get an optimal output in a more sustainable manner.

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Chapter 10

VERMICULTURE TECHNOLOGY FOR RECYCLING OF SOLID WASTES AND WASTEWATER BY EARTHWORMS INTO VALUABLE RESOURCES FOR THEIR REUSE IN AGRICULTURE (ORGANIC FARMING) WHILE SAVING WATER AND FERTILIZER

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ABSTRACT

A revolution is unfolding in studies about earthworms (Sir Charles Darwin's 'unheralded soldiers of mankind) for biological recycling of all human wastes (solid wastes and wastewater) and using the recycled products and resources generated (vermicompost, treated nutritive water and earthworm biomass) to promote sustainable agriculture (organic farming) without agro-chemicals. The conventional methods of solid waste management of disposal in 'engineered landfills', wastewater treatment of treatment plants with sludge generation (Biohazard) and their disposal in securing landfills are all highly expensive and also affect the environment by emitting huge pollutants and greenhouse gases inducing global warming. Construction of engineered landfills incurs 20-25 million US dollars upfront before the first load of waste is dumped. Landfill emits toxic trace gases like 'xylene' and 'toluene' and powerful greenhouse gases like methane (CH_4) and nitrous oxides (N_2O). STPs also emit CH_4 and N_2O. Molecule to molecule methane is 22 times and nitrous oxides 312 times more powerful than carbon dioxide. In 2005, landfill disposal of MSW contributed 17 million tons CO_2-e (equivalent) of GHG in Australia, equivalent to the emissions from 4 million cars or 2.6% of the national GHG emissions.

Earthworm enhances natural degradation and decomposition of organic waste from 60 to 80% and the process becomes faster with time as the army of degrader worms grows, further proliferating several battalions of the aerobic decomposer microbial army. Vermicomposting can divert 60-70% MSW from landfills. Earthworms' bodies work as a 'BIOFILTER' and can treat all municipal and several industrial wastewaters removing the BOD_5 by over 90%, COD by 80-90%, TDS by 90-92% and the TSS by 90-95% of wastewater. Vermifiltration involves very 'low energy' as there is no churning and aeration of wastewater and no formation of 'sludge'.

We have successfully experimented in Vermicomposting of various solid wastes, even 'hazardous sewage sludge' from Sewage Treatment Plants and 'cement sludge and silica dust' from Cement Board Industries'. We also successfully experimented in 'Vermifiltration of 'Municipal and Industrial Wastewater' (even the most toxic petroleum industry wastewater). The end-products (Vermicompost and Vermifiltered Clean Water) generated were re-used for growth of cereal and vegetable crops with amazing results. Growths of crop plants are enhanced by 30–40% higher over the chemical fertilizers with highly reduced incidences of pests and diseases. Nutritive values of the Grains, Fruits and Vegetables grown on Vermicompost also increase.

Keywords: Earthworms, solid wastes vermicomposting, wastewaters vermifiltration; disinfected & detoxified nutritive vermifiltered water for farm irrigation; NKP & beneficial microbe rich vermicompost for organic farming

1. INTRODUCTION

Mounting municipal solid wastes (MSW) is a problem that threatens the global human society and is increasing with the growing human population and the culture of consumerism worldwide. Plastics have added to the problem. We are facing the escalating socioeconomic and environmental cost of dealing with current and future generations of mounting MSW. Waste management either by landfill disposal or incineration (to generate electricity) is environmentally highly destructive and economically prohibitive. Construction of engineered landfills incurs 20-25 million US dollars upfront before the first load of waste is dumped.

Further, the landfills have to be monitored for at least 30 years for emissions of toxic and greenhouse gases and toxic leachate (waste juice). During 2002 – 2003, waste management services within Australia cost $2458.2 million. Over the past 5 years the cost of landfill disposal of waste has increased from $29 to $65 per ton of waste in Australia. (Australian Bureau of Statistics, 2004). Of greater environmental concern is that landfill emit huge and more powerful greenhouse gases like methane and nitrous oxides which are respectively (molecule to molecule) 22 and 312 times more powerful than carbon dioxide. They also emit highly toxic trace gases like 'toluene and xylene'. Incineration emits dangerous 'dioxins and furans' (mainly due to plastics) for which WHO has 'no safe limits' for mankind. A greater part of MSW contains 'waste organics' which can be composted.

Increasing municipal and industrial wastewater is also a serious problem worldwide. Vermifiltration of wastewater using waste-eater earthworms is a newly conceived novel technology with several advantages over the costly conventional sewage treatment plants (STPs) like 'Activated Sludge', 'Aerated Lagoons' and 'Rotating Biological Contactors'. We have pioneered the technology in Australia (2007).

2. Solid Waste Recycling by Earthworms: Degrade MSW into Disinfected and Detoxified Vermicompost Rich in Humus, Essential Nutrients and Beneficial Soil Microbes

Vermicomposting of wastes organics by waste eater earthworms is proving to be economically and environmentally preferred recycling technology over the conventional microbial composting technology as it is rapid and nearly odorless process, reducing composting time by more than half and the end product is both 'disinfected', 'detoxified' and 'highly nutritive' vermicompost (a bio-fertilizer) which is a sustainable alternative to the destructive chemical fertilizers (Discussed below). It diverts 60-70% MSW from landfills. Earthworms have dual action on waste organics – secrete enzymes (amylase, lipase, cellulase and chitinase) to degrade organics and engineers the growth of 'decomposer microbes' in billions and trillions in short time. Given the optimum conditions of temperature (20-30 °C) and moisture (60 - 70%), about 5 kg of worms (numbering approx. 10, 000) can vermiprocess 1 ton of organic wastes into vermicompost in just 30 days and the process becomes faster with time. Vermicomposting leads to generation of 'huge worm biomass' as the worms multiply rapidly. It is a valuable resource now finding new applications in feed and pharmaceutical industries(Sinha et al. 2002; Sinha et al. 2011 a).

Solid waste from paper pulp and cardboard industry, food processing industries including brewery and distillery; vegetable oil factory, sugarcane industry, aromatic oil extraction industry, sericulture industry, logging and carpentry industry also make excellent feedstock for vermicomposting. Worms can also degrade 'fly-ash and sewage sludge' (a Biohazard from coal power and sewage treatment plants) into wonderful vermicompost. They have also been found to degrade toxic 'asphaltens' from the oil drilling sites. They are all safely disposed without landfills.

2.1. Some Studies on Waste Recycling by Earthworms by Vermicomposting

1) Kale and Sunitha (1995) successfully studied the vermicomposting of solid wastes from Aromatic Oil Extraction Industry. They also studied vermicomposting of wastes from Mining industries, which contains ‘sulfur residues’ and creates disposal problems. Such wastes can also be fed to the earthworms mixed with organic matters. The optimum mixing ratio of the sulfur waste residues to the organic matter was 4%.
2) Saxena et al. (1998) studied the vermicomposting of ‘fly-ash’ from the Coal Power plants which is a hazardous waste and poses a serious disposal problem due to heavy metal contents. They found that 25% of fly-ash mixed with sisal green pulp, *Parthenium* sp. and green grass cuttings formed excellent feed for *Eisenia fetida* and the vermi-compost was higher in NKP. The earthworms also ingested the heavy metals from the fly-ash.
3) Bajsa et al. (2004) studied vermicomposting of ‘Human Excreta’ (feces). It was completed in six months, with good physical texture, odourless and safe pathogen quality. Sawdust provide best covering material with a good earthy smell, a crumbly texture and dark brown color. There was no re-growth of pathogens on storing the vermicompost for longer time. They also studied the pathogen die-off in vermicomposting of sewage sludge spiked with *E. coli*, *S. typhimurium* and *E. faecalis* at the 1.6-5.4 × 10^6 CFU/g, 7.25 × 10^5 CFU/g and 3-4 × 10^4 CFU/g respectively. The composting was done with different bulking materials such as lawn clippings, sawdust, sand and sludge alone for a total period of 9 months. Safe end-products were achieved in 4-5 months of vermicomposting.
4) Sinha et al. (2010 b) studied vermicomosting of hazardous Sewage Sludge. They feed readily upon the sludge components and rapidly convert them into vermicompost. They significantly reduced the heavy metals cadmium (Cd) and lead (Pb) from the digested sludge and almost eliminated the pathogens. It showed ‘negative results’ by the Colilert test under the UV lamp. Volume was also reduced from 1 cum of wet sludge (80% moisture) to 0.5 cum of vermicompost (30% moisture). And this was all achieved in just 12 weeks.
5) Scholder (2011) in the USA is vermicomposting sewage sludge meeting the requirements of the EPA. The ‘wet biosolids’ was converted into a ‘dry biosolid’ with 75-80% weight reduction within 24 – 72 hours. The worms used were ‘Redworms’.
6) We also studied the vermicomposting of Fiber Cement Sludge and Silica dust by *Eisenia fetida*. Millions of tons of this waste from the Cement Board Manufacturing Industries are ending up as ‘industrial wastes’ in the landfills in Australia every year. Similarly, huge amounts of pineapple pulp and effluent mud (after washing of pineapples in fruit juice processing industries) also end up in the landfills. These farms and industrial wastes were vermicomposted with multiple objectives for the environment and society, converting ‘waste into resource while diverting wastes from landfills’ thus benefiting both economy and ecology of Australia.

Following four combinations of waste materials were studied for vermicomposting.

a. 50% (Effluent Mud + Fiber Cement Sludge + Silica Dust in equal proportions) and 50% Organics (Pineapple Pulp)
b. 75% (Effluent Mud + Fiber Cement Sludge + Silica Dust in equal proportions) and 25% Organics (Pineapple Pulp)
c. 50% (Effluent Mud + Fiber Cement Sludge + Silica Dust in equal proportions) and 50% Organics (Pineapple Pulp) With Cow Manure as ADDITIVES.
d. 75% (Effluent Mud + Fiber Cement Sludge + Silica Dust in equal proportions) and 25% Organics (Pineapple Pulp) With Cow Manure as ADDITIVES.

About 20 kg of each combination of materials were taken in plastic trays and subjected to vermiprocessing by earthworms (*Eisenia fetida*) obtained from the market. In each tray about 500 healthy adult earthworms were released. The moisture content of the materials was kept around 60-70%. The pH was near neutral.

The earthworms successfully degraded the waste materials in all combinations, but the best results were obtained in combination (b) i.e., 75% (Effluent Mud + Fiber Cement Sludge + Silica Dust in equal proportions) and 25% Organics (Pineapple Pulp). The end product was blackish-gray 'vermicompost'. This was achieved in about 15 weeks. There was significant increase in the number of earthworms in this combination which was a bio-indicator that the worms loved these wastes as their 'food'.

2.2. Mechanism of Worm Action in Solid Waste Degradation

Earthworms act as an aerator, grinder, crusher, chemical degrader and a biological stimulator in the environment in which they live and operate. (Dash, 1978; Binet et al., 1998 and Sinha et al., 2002). Worms degrade waste by 'multiple action'. First, grind the waste by 'muscular action' followed by breaking the waste organics by 'enzymatic action' and then by the action of 'decomposer microbes' which is proliferated by the earthworms in the composting system in billions and trillions.

a. Worms Reinforce Microbial Population and Act Synergistically Promoting Rapid Waste Degradation

Earthworms promote the growth of 'beneficial decomposer microbes' (bacteria, actinomycetes and fungi) in waste biomass and this they do with improving aeration by burrowing actions. They also act as an aerator, grinder, crusher, chemical degrader and a biological stimulator. (Dash, 1978; Binet et al., 1998 and Sinha et al., 2002). Earthworms host millions of decomposer (biodegrader) microbes in their gut which is described as 'little bacterial factory'. They devour on microbes and excrete them out as vermicast (many times more in number than they ingest) in soil along with nutrients nitrogen (N) and phosphorus (P) in their excreta (Singleton et al., 2003). The nutrients N and P are further used by the microbes for multiplication and vigorous action. Edward and Fletcher (1988) showed that the number of bacteria and 'actinomycetes' contained in the ingested material increased up to 1000 fold while passing through the gut. A population of worms numbering about 15,000 will in turn foster a microbial population of billions of millions in excreta (vermicast). (Morgan and Burrows, 1982). Worm vermicast is high in degrader microbes and thus high in catabolic activities. Teotia et al., (1950) reported 32 million bacterial counts per gram of vermicast as compared to 6-9 million/gram in surrounding soils. Singleton et al. (2003) studied the bacterial flora associated with the intestine and vermicasts of the earthworms and found species like *Pseudomonas, Mucor, Paenibacillus, Azoarcus, Burkholderia, Spiroplasm, Acaligenes,* and *Acidobacterium* which has potential to degrade several categories of organics. *Acaligenes* can even degrade PCBs and *Mucor* can degrade dieldrin.

Under favorable conditions, earthworms and microorganisms act 'symbiotically and synergistically' to accelerate and enhance the decomposition of the organic matter in the waste. It is the microorganisms which break down the cellulose in the food waste, grass clippings and the leaves from garden wastes. (Morgan and Burrows, 1982; Xing et al. 2005)

b. Worms Degrade Waste by Grinding Action

The waste feed materials ingested is finely ground (with the aid of stones in their muscular gizzard) into small particles to a size of 2-4 microns and passed on to the intestine for enzymatic actions. The gizzard and the intestine work as a 'bioreactor';

c. Worms Degrade Waste by Enzymatic Action

The worms secrete enzymes proteases, lipases, amylases, cellulases and chitinases in their gizzard and intestine, which bring about rapid biochemical conversion of the cellulosic and the proteinaceous materials in the waste organics. Earthworms convert cellulose into its food value faster than proteins and other carbohydrates. They ingest the cellulose, pass it through its intestine, adjust the pH of the digested (degraded) materials, cull the unwanted microorganisms, and then deposit the processed cellulosic materials mixed with minerals and microbes as aggregates called 'vermicasts' in the soil. (Dash, 1978).

Only 5-10 percent of the chemically digested and ingested material is absorbed into the body and the rest is excreted out in the form of fine mucus coated granular aggregates - the 'vermicasts' rich in nitrates, phosphates and potash.

d. Worms Humify the Degraded Wastes

The final process in vermi-processing and degradation of organic matter is the 'humification' in which the large organic particles are converted into a complex amorphous colloid containing 'phenolic' materials. Only about one-fourth of the organic matter is converted into humus. The colloidal humus acts as 'slow release fertilizer'. (Visvanathan et al. 2005).

2.3. Advantages of Waste Recycling by Vermicomposting Over Conventional Composting

Earthworms have real potential to both increase the rate of aerobic decomposition and composting of organic matter by over 75% and also to stabilize the organic residues in the MSW and sludge – removing the harmful pathogens and heavy metals from the compost (Hartenstein et al., 1980; Pierre et al. 1982; Ireland, 1983). The quality of compost is significantly improved, rich in key minerals and beneficial soil microbes (Edwards, 2000). In fact, in the conventional aerobic composting process which is thermophilic (temperature rising up to 55°C) many beneficial microbes are killed and nutrient, especially nitrogen is lost (due to gassing off of nitrogen). Earthworms create aerobic conditions in the waste materials by their burrowing actions, inhibiting the action of anaerobic micro-organisms which release foul-smelling hydrogen sulfide and mercaptans. The earthworms release coelomic fluids that have anti-bacterial properties and destroy all pathogens in the resulting compost. (Pierre et al., 1982). The greatest advantage over the conventional composting system is that the end product is more homogenous, richer in ‘plant-available nutrients and humus’ and significantly low contaminants (disinfected and detoxified). They are ‘soft’, ‘highly porous’ with greater ‘water holding capacity’ (Hartenstein and Hartenstein, 1981; Appelhof, 1997;Lotzof, 2000).

2.4. Commercialization of Vermicomposting Technology to Reduce Landfills and Use Vermicompost in Agriculture to Replace the Destructive Agrochemicals

Vermicomposting for diverting wastes from landfills and use of vermicompost in agriculture is being commercialized all over the world for mid to large scale vermicomposting of most organic wastes (food and farm wastes and green wastes and also the hazardous wastes like sewage sludge and fly-ash) from developed countries like the U.S., Canada, U.K., Australia, Russia and Japan to developing countries like India, China, Chile, Brazil, Mexico, Argentina and the Philippines (Bogdanov, 1996; Sherman, 2000). A large scale vermicomposting plants have been installed in the US and Canada to vermicompost municipal and farm wastes and use the vermicompost and other vermiproducts for ‘organic farming’ (GEORG, 2004; Hahn, 2011). UK is promoting vermicomposting mainly for waste management and to reduce the needs of ‘waste landfills’. Large 1000 metric ton vermicomposting plants have been erected in Wales to compost diverse organic wastes (Frederickson, 2000). France is also promoting vermicomposting on a commercial scale to manage all its MSW and reduce the needs of landfills. In France, several tons of mixed household wastes are being vermicomposted everyday using 1000 to 2000 million red tiger worms (*Eisenia andrei*). (Visvanathan et al., 2005). The ‘Envirofert Company’ of New Zealand is vermicomposting about 5-6 thousand tons of green waste every year. They are also vermicomposting approximately 40,000 tons of food wastes from homes, restaurants and food processing industries every year. (www.envirofert.co.nz) (Gary, 2011).

Vermiculture is being practiced and propagated on a large scale in Australia to divert waste from landfills. Several vermiculture companies have also come up in Australia. (Lotzof, 2000; Dynes, 2003). Vermicomposting is going on in a large scale in India to use vermicompost (and vermiwash liquid) in farms and replace the destructive and costly agrochemicals. The Karnataka Compost Development Corporation in India established a first vermicomposting unit in the country to handle all municipal urban solid wastes and is producing 150 to 200 tons of vermicompost every day from city garbage. (Kale 2005). Several vermicomposting companies have come up in the states of Bihar, Punjab, Gujarat and Tamil Nadu supplying vermicompost all over India.

Waste materials preferably to be avoided for vermi-composting

1) Heavily salted products unless soaked in water for 24 hours;
2) Excess citrus (orange and lemon peels and crushes) and onion wastes (might reduce pH and impair worm activity);
3) Feces of pets (may carry viral or bacterial toxins);
4) Fresh green grass (creates high temperature and can harm worms);
5) All non-biodegradable wastes;
6) Meat and dairy products and slaughterhouse waste are to be avoided in the initial stage till the number of earthworms becomes high enough in the composting bed (it may invite 'maggots' and also create bad odors for sometimes).

3. Wastewater Recycling by Earthworms: Purify Wastewater into Disinfected and Detoxified Clean Water for Reuse in Agriculture

Earthworms body work as a 'biofilter' removing BOD_5 by over 95%, COD by 55% - 85%, TSS by 90-95%, turbidity by over 95% from wastewater. Worms also 'bio-accumulate' any toxic chemicals, including heavy metals and toxic organics. Worms kill the pathogens in the wastewater by their anti-pathogenic ceolomic fluid and the fecal Coliforms are removed by over 99%. The treated water becomes 'detoxified' and 'disinfected' and clean enough to be 'reused' for non-potable purposes, e.g., washing, cleaning, industrial uses and for farm irrigation as they are highly 'nutritive' rich in NKP.

Earthworms in the vermifilter bed feed upon the solids in wastewater and excrete them as 'vermicast'. Worm vermicasts also provide wonderful sites for 'adsorption' of heavy metals and organic pollutants in wastewater. This is due the presence of 'hydrophilic' groups in the 'lignin contents' and 'humus' of the vermicompost (Bolan and Bhaskaran,1996). The vermicast also offers excellent 'hydraulic conductivity' of sand (being porous like sand) and also high 'adsorption power' of clay. (Bhawalkar, 1995).

We have also successfully treated some industrial wastewater dairy, brewery and fruit juice industry (with very high BOD loads) including most toxic 'petroleum wastewater' by *E. fetida*. Our technology has been commercialized in India for treatment of 400 KL 'sewage' every day and they are being reused by farmers for irrigation in agriculture (Discussed below).

3.1. Worm Population and Density (Biomass) in Vermifilter Bed

As the earthworms play the critical role in wastewater purification their numbers and population density (biomass) in vermifilter bed, maturity and health are important factors. This may range from several hundred to several thousands. Studies indicate that about 8-10,000 numbers of worms per square meter of the vermifilter bed and in quantity (biomass) as 10 kg per cubic meter (cum) of soil in the VF bed for optimal function.

3.2. Hydraulic Retention Time (HRT)

Hydraulic retention time is the time taken by the wastewater to flow through the soil profile (vermifilter bed) in which earthworms inhabits. It is very essential for the wastewater to remain in the vermifiltration (VF) system and be in contact with the worms for a certain period of time. HRT depends on the flow rate of wastewater to the vermifiltration unit, the volume of soil profile and quality of soil used. HRT is very critical, because this is the actual time spent by earthworms with wastewater to retrieve organic matter from it as food. During this earthworms carry out the physical and biochemical process to remove nutrients, ultimately reducing BOD, COD and the TDSS. The longer wastewater remains in the system in contact with earthworms, the greater will be the efficiency of vermi-processing and retention of nutrients. Hence the flow of wastewater in the system is an important consideration as it determines the retention of suspended organic matter and solids (along with the chemicals adsorbed to sediment particles). Maximum HRT can result from ‘slower rate of wastewater discharge’ on the soil profile (vermifilter bed) and hence slower percolation into the bed. Increasing the volume of soil profile can also increase the HRT. The number of live adult worms, functioning per unit area in the vermifilter (VF) bed can also influence HRT.

High hydraulic loading rate leads to reduced hydraulic retention time (HRT) in soil and could reduce the treatment efficiency. Hydraulic loading rates will vary from soil to soil. The infiltration rates depend upon the soil characteristics defining pore sizes and pore size distribution, soil morphological characteristics, including texture, structure, bulk density, and clay mineralogy.

3.3. Some Experimental Studies on Waste Water Recycling and Purification by Earthworms

1) Soto and Toha (1998) were pioneer workers on vermifiltration of wastewater. They studied in a pilot plant for treating Sewage of 1000 inhabitants and found that the BOD load was removed by 99%, TSS by 95%, VSS by 96%, nitrogen (N) by 89% and phosphorus (P) by 70%. The vermifilter bed was prepared of stones at the bottom and sawdust above with 20-30 cm humus in the top in which 5000 -10,000 earthworms (Eisenia andrea) per square meter were released. E. coli (M.P.N.) was removed by 1000 fold. Such systems allowed to treat 1000 L/m^2/of wastewater per day. Over 100 VFT Plants are now operating in Chile, Mexico and Venezuela.
2) Xing et al. (2005) at Shanghai Quyang Wastewater Treatment Facility in China studied vermifiltration of sewage. The vermifilter bed 1m (long) x 1m (wide) x 1.6m (high) was composed of granular materials and earthworms number were about 8000 worms/sqm. The average chemical oxygen demand (COD) of raw sewage was 408.8 mg/L, that of 5 days biological oxygen demand (BOD_5) was 297 mg/L, the suspended solids (SS) were 186.5 mg/L. The hydraulic retention time (HRT) varied from 6 to 9 hours and the hydraulic loading from 2.0 to 3.0 m^3/(m^2.d) of sewage. The removal efficiency of COD ranged between 81-86%, the BOD_5 between 91-98%, and the SS between 97 - 98%.

3) Sinha et, al., (2008 a) studied the vermifiltration of sewage obtained from the Oxley Wastewater Treatment Plant in Brisbane, Australia. Results showed that the earthworms removed BOD_5 loads of sewage by over 99% at HRT in 1-2 hours. Average COD removed from the sewage was over 50%, which was not very signify-cant, but at least much higher than the control. Earthworms also removed the total suspended solids (TSS) from the sewage by over 90%.
4) Sinha and Bharambe (2007) studied the vermifiltration of brewery and milk dairy wastewaters which have very high BOD_5 and TSS loadings e.g., 6780 mg/L and 682 mg/L respectively from brewery and 1,39,200 mg/L and 3,60,00 mg/L respectively from the dairy industry. Earthworms removed the high BOD_5 loads by 99% in both cases and TSS by over 98%. But the hydraulic retention times (HRTs) in case of brewery wastewater was 3-4 hours and 6-10 hours for the dairy wastewater.
5) Xing et al., (2010) at Tongji University, Shanghai, China reported good performance of vermifilter system packed with ‘quartz sands and ceramsite’ for domestic wastewater treatment. The removal rates for COD were 47.3 - 64.7%; for BOD_5 were 54.78 - 66.36%; for SS were 57.18 – 77.90%; total nitrogen were 7.63 - 14.90%; and NH_4-N were 21.01 - 62.31%, respectively.
6) Sinha (2011 c) studied vermifiltration of petroleum contaminated toxic wastewater obtained from automobile service industry in Brisbane. The wastewater was blackish-brown with pungent odor. It contained a mixture of ‘aliphatic’ and ‘aromatic’ volatile petroleum hydrocarbons (C 10 - C 36) and ‘organochlorines’ originating from the cooling liquids, waste engine and gear oil, waste transmission and brake fluid, grease, spilled petrol and diesel oil. The aliphatic fraction contained the majority of petroleum compounds, e.g., cycloalkanes, as well as an unresolved complex mixture of saturated toxic hydrocarbons. The aromatic fraction mainly consisted of PAHs and is more toxic and persistent than the aliphatic part. Worms not only tolerated and survived in the toxic environment, but also vermi-filtered and vermi-remediated the ‘dark brown’ petroleum wastewater into ‘pale yellow’ and odorless water indicating the disappearance of all complex hydrocarbons. On the second run, the ‘pale yellow’ color disappeared and ‘clear water’ was obtained.
7) Sinha et al. (2013) studied the vermifiltration of wastewaters from Fruit Juice Processing Industries in Brisbane. They are high in BOD and COD values. COD was reduced from 2730 mg/L to 112 mg/L (95.89%), BOD_5 from 1340 mg/L to 3 mg/L (99.77%), Turbidity from 130 NTU to 6 NTU (95.38%), TSS of 190 mg/L to 16 mg/L (91.57%), TDS from 440 mg/L to 12 mg/L (95.89%) and Conductivity from 840 ms/cm to 26 ms/cm (96.90%).
8) Sinha et al. (2014) also studied the vermifiltration of wastewaters from Coalmine Washeries in Australia. The suspended solids (SS) were reduced from 5850 mg/L to 31 mg/L and the Chemical Oxygen Demand (COD) was reduced from 1210 mg/L to 204 mg/L. Among heavy metals Cd was reduced from 0.0016 to 0.0003; As from 0.018 mg/L to 0.007 mg/L; Cr from 0.023 mg/L to 0.002 mg/L; Pb from 0.088 mg/L to <0.001; Zn from 0.962 mg/L to 0.022; Al from 28.3 mg/L to 0.12 mg/L and Mo from 0.107 mg/L to 0.004 mg/L.

3.4. Mechanism of Worm Action in Vermifiltration

1) The twin processes of microbial stimulation and biodegradation, and the enzymatic degradation of waste solids by worms as discussed above simultaneously work in the vermifiltration system too.

2) Vermifilters provide a highly specific area – up to 800 sq m/g and voidage up to 60%. Suspended solids are trapped on top of the vermifilter and processed by earthworms and fed to the soil microbes immobilized in the vermifilter.

3) Dissolved and suspended organic and inorganic solids are trapped by adsorption and stabilized through complex biodegradation processes that take place in the 'living soil' inhabited by earthworms and the aerobic microbes. Intensification of soil processes and aeration by the earthworms enable the soil stabilization and filtration system to become effective and smaller in size.

4) Earthworms intensify the organic loadings of wastewater in the vermifilter soil bed by the fact that it granulates the clay particles, thus increasing the 'hydraulic conductivity' of the system. They also grind the silt and sand particles, thus giving high total specific surface area, which enhances the ability to 'adsorb' the organic and inorganic from the wastewater passing through it.

5) Vermicompost (produced by earthworms in the vermifilter bed through the feeding of solids in wastewater and their excretion as 'vermicast') provides wonderful sites for 'adsorption' of heavy metals and pollutants in wastewater. This is due the presence of 'hydrophilic' groups in the 'lignin contents' and 'humus' of the vermicompost. The worm vermicast also offers excellent hydraulic conductivity of sand (being porous like sand) and also a high adsorption power of clay. (Bhawalkar, 1995).

6) Earthworms also graze on the surplus harmful and ineffective microbes in the wastewater selectively, prevent choking of the medium and maintain a culture of effective 'bio-degrader microbes' to function.

3.5. Advantages of Vermifiltration System Over Conventional Wastewater Treatment Systems

Vermi-filtration of wastewater is low energy and efficient system and has a distinct advantage over all the conventional wastewater treatment systems - the 'Activated Sludge Process', 'Trickling Filters' and 'Rotating Biological Contactors' which are highly energy intensive, costly to install and operate and do not generate any income. The greatest advantage of the system is that it uses much less 'energy' and there is no formation of 'sludge' which is a 'Biohazard' requiring safe disposal at high cost. The capital and operating costs are hence much less by over 70% than other sewage treatment plants (STPs) and is very suitable for developing nations, including India where STPs often remains idle due to shortage of power.

In the vermifilter process there is a 100% capture of organic materials by earthworms and it is converted into vermicompost. The capital and operating costs are less, and the end products (vermifiltered disinfected and detoxified nutritive water) and byproducts (the nutritive water, vermicompost and earthworms biomass) are of additional economic uses in agriculture and for promoting poultry, fishery and dairy as the worms are highly nutritive feed materials containing about 60% protein rich in all essential amino acids.

a. No Sludge Formed as Worms Feed on Wastewater Solids to Form Vermicompost

This plague most municipal councils in the world as the sludge is a 'Biohazard' and requires safe landfill disposal at high cost. The greatest advantage of vermifiltration system is that there is no formation of 'sewage sludge' (Huges et al., 2005). The worms decompose the organics in the wastewater and also devour the solids (which forms the sludge) synchronously. They feed readily upon the sludge components, rapidly convert them into vermicompost, reduce the pathogens to safe levels and ingest the heavy metals. In all developed nations a 'worm farm' has become a necessity in all wastewater and water treatment plants to resolve the sludge problems.

b. No Foul Odor

There is no foul odor as the earthworms arrest rotting and decay of all putrescible matters in the wastewater and the sludge. The ammoniacal nitrogen **(NH_4-N)** is significantly reduced in the vermifiltered water by nearly 99%.

c. Worms Disinfect and Detoxify Wastewater Rendering Fit for Reuse in Agriculture

Vermifiltered water is free of pathogens and toxic chemicals (heavy metals and endocrine disrupting chemicals) and suitable for 'reuse' as water for non-potable purposes in industries and agriculture for irrigation. The worms devour on all the pathogens (bacteria, fungus, protozoa and nematodes) in the medium in which they inhabit. They have the capacity to bio-accumulate high concentrations of toxic chemicals, including heavy metals and organic pollutants in their tissues and the resulting wastewater becomes almost chemical-free. (Ireland, 1983; Hartenstein et al., 1980; Haimi et al., 1992). Their bio-transform the heavy metals by combining them with special proteins called 'metallotheanine' and biodegrade the toxic organics rendering them all harmless by enzymatic actions.

The dissolved oxygen (DO) values which are NIL in raw sewage are increased to 4-5 ppm good enough for survival of aquatic organisms & re-use in agriculture.

d. Worms Remove Endocrine Disrupting Chemicals from Sewage

Earthworms have also been reported to bio-accumulate 'endocrine disrupting chemicals' (EDCs) from sewage which otherwise is not removed by our conventional sewage treatment plants (STPs). Markman et al. (2007) have reported significantly higher concentrations of EDCs (dibutylphthalate, dioctylphthalate, bisphenol-A and 17 β - estrdiol) in tissues of earthworms (*E. fetida*) living in sewage percolating filter beds and also in garden soil.

3.6. Commercialization of Vermifiltration Technology to Treat and Recycle Wastewater Economically and Reuse of Recycled Water in Agriculture Saving Fresh Water

Due to its simplicity and cost-effectiveness vermifiltration of both municipal and industrial wastewater is destined to become a global movement. In Chile, over 100 sewage treatment plants of different sizes, going from individual houses to plants for 12,000 persons and bigger plants for industries are already working. It has been introduced on a commercial scale in Mexico and Venezuela (Soto and Toha, 1998). India and Brazil are also introducing the technology on a commercial scale. It is being considered in Russia, China and Zimbabwe too for decentralized treatment of wastewater. China is also considering our Vermifiltration Technology for purification of polluted rivers.

Inspired by our publication on vermifiltration technology (Sinha et al., 2008 a) the TRANSCHEM Agritech Ltd. in India has also commercialized the technology and installed a 'Vermifiltration Plant' in Bhavnagar, Gujarat for treatment and recycling of 400 KL sewage every day in about 400 sqm of land transformed into Bio-filter (Vermifilter). (See on YOU-TUBE – 'Wastewater Treatment by Earthworms Rajiv Sinha '). The treated water is being supplied to farmers.

Over 30 Vermifilter Plants have been installed till date for treatment of both municipal and industrial wastewaters in Gujarat state of India. The VF bed contains various grades of pebbles below in an inclined base (to drain the treated water) covered by layers of soil, sawdust, agric. materials and vermicompost (humus) in which resides the waste-eater earthworms. The sewage is collected in an adjoining tank, pumped into the bio-filter and sprayed over the VF bed by sprinklers. No aeration or pre-treatment of sewage is required. The treated water is collected in another adjoining tank and supplied to farmers. On average the BOD is being removed by over 95%, COD over 85%, TSS and Turbidity over 95% and fecal coliforms by over 99%. The TDS is removed only by 16%. High TDS is due to anions – nitrates, sulphates, chlorides and carbonates. Nitrates and sulfates are good for water for farm irrigation. Higher chlorides are due to the geographical location of the VFT plant which is closer to the seas. The value is however, acceptable for farm irrigation in India. Ammoniacal nitrogen (NH_4-N) from the raw sewage (creating foul odor) is reduced from 25-40 ppm to less than 1 ppm and the total phosphorus (causing eutrophication and algal bloom) from 4-8 ppm to 1-2 ppm. But the useful Nitrates (NO_3), Phosphates (P_2O_5) and Potassium (K) increase significantly.

4. Agricultural Use of the End-products of Recycled Wastes and Wastewater by Earthworms: When HUMAN WASTES are Converted into WEALTH (Nutritive Water and Organic Fertilizer)

Earthworms convert both SOLID WASTES and WASTEWATER into valuable RESOURCE (Vermicompost and Disinfected, Detoxified Clean Water). Vermicompost is highly nutritive ORGANIC FERTILIZER much superior to all Organic Fertilizers and even the Chemical Fertilizers. Its use of the farm soil eventually generates large numbers of EARTHWORMS from their cocoons which works as the 'natural ploughman' and fertilizing agent in the farm soil.

In the Vermifiltered water the useful nitrates (NO_3) are increased from 10-20 ppm to over 50 ppm, the useful bio-available phosphates (P_2O_5) from 1-2 ppm to 5-7 ppm and the potassium (K) from 10-15 ppm to 20-25 ppm. The treated water becomes highly nutritive and good enough to be used in agriculture for farm irrigation with considerable savings on fertilizers. As agriculture uses nearly 80% of fresh water in the world, it would lead to tremendous savings of groundwater resources.

Huge 'EARTHWORM BIOMASS' also results as the worms multiply very fast. Earthworms are finding new applications in various industries as raw materials for 'development of life saving medicines' especially for the 'cure of cancer' and 'heart disease'; development of 'nutritive feed materials' for fishery and dairy industries and raw materials for 'rubber, lubricants, soaps and detergent industries'.

4.1. Vermicompost: An Excellent Biofertilizer to Promote ORGANIC FARMING

Earthworms and its vermicompost make the soil 'soft and porous' (by burrowing actions) and restore its physical, chemical and biological properties to improve its natural fertility and productivity. It also increases the 'water holding' capacity of the farm soil. Earthworms vermicompost work as an excellent biofertilizers at least 5-7 times more nutritive than all other composts and gives 30-40% higher crop yields over chemical fertilizers. It also contains 'plant growth hormones' (auxins, gibberlins and cytokinins). Earthworms and its vermicast also engineers 'biological resistance' in plants against pests and diseases due to 'actinomycetes', repels insect pests and suppress plant diseases' in crops and 'inhibit the soil-born fungal diseases' due to 'chitinases'. Vermicompost consistently improve seed germination, enhance seedling growth and development. The biggest advantage of great social and economic significance is that the food produced is completely 'organic and chemical-free' and the amount of use of vermicompost is gradually reduced in future as the 'natural fertility' of the soil is restored and increases over time.

Vermicompost also has very 'high porosity', 'aeration', 'drainage' and 'water holding capacity' than the conventional compost. This is mainly due to the 'humus content' present in the vermicompost. Thus vermicompost use reduces the requirement of water for irrigation by 30-40%. Another big advantage of great economic and environmental significance is that production of vermicompost (locally from community wastes) is at least 75% cheaper than the chemical fertilizers (produced in factories from vanishing petroleum products generating waste and pollution). And over successive years of application, vermicompost 'build-up the soil's natural fertility' improving its total physical, chemical and biological properties. On the contrary, with the continued application of chemical fertilizers over the years the 'natural fertility of soil is destroyed' and it becomes 'addict'. The subsequently greater amount of chemical is required to maintain the same yield and productivity of previous years.

Another advantage of great environmental significance is that vermicompost 'suppresses plant disease' in crops and inhibits the soil-born fungal diseases. In field trials with pepper, tomatoes, strawberries and grapes, significant suppression of plant-parasitic nematodes have been found. There is also a significant decrease in arthropods (aphids, buds, mealy bug, spider mite) populations with 20% and 40% vermicompost additions. (Edwards and Arancon, 2004). Humus in vermicast extracts 'toxins', 'harmful fungi and bacteria' from soil and protects plants. Actinomycetes in vermicast induces 'biological resistance' in plants against pests and diseases. Such as use of vermicompost significantly reduces the need for 'chemical pesticides'.

4.2. Some Studies on Use of Vermicompost in Improving Farm Production

Studies at CSIRO Australia found that the earthworms and vermicompost can promote growth of wheat crops by 39%, grain yield by 35%, lift the protein value of the grain by 12% and fight crop diseases. More significantly, it reduced the demand for water irrigation by nearly 30-40% as the 'water holding' capacity of the soil was also increased by the use of vermicompost.(Baker and Barrett, 1994; Baker et al., 1997). Buckerfield and Webster (1998) found that vermicompost boosted grape yield by two-fold as compared to chemical fertilizers. Treated vines with vermicompost produced 23% more grapes. Significantly, the yield was greater by 55% when vermicompost applied soil was covered under mulch of straw and paper. Still more significant was that 'single application' of vermicompost had positive effects on yields of grapes for long 5 years. Arancon et, al., (2004) found that the 'yield' of marketable strawberries and the 'weight' of the 'largest fruit' was greater on plants in plots grown on vermicompost as compared to inorganic fertilizers in 220 days after transplanting. Also, there were more 'runners' and 'flowers' on plants grown on vermicompost.

Webster (2005) found that the use of vermicompost on cherries increased yield of 'cherries' for three (3) years after 'single application' inferring that the use of vermicompost in soil builds up fertility and restore its vitality for long time and its further use can be reduced to a minimum after some years of application in farms.

Sinha et al. (2009 and 2010 a) also studied the growth impacts of vermicompost on farm wheat crops in India. Vermicompost supported yield better than chemical fertilizers and had other agronomic benefits. It significantly reduced the demand for irrigation by nearly 30-40%. Soil tests indicated better availability of essential micronutrients and useful microbes. There was significantly 'less incidence of pests and disease attacks' in vermicompost applied crops which reduced use of chemical pesticides by over 75%.

4.3. Vermicompost Produce Nutritive and Health Protective Organic Foods

Studies made at CSIRO (Council of Scientific and Industrial Research Organization), Australia found that the presence of earthworms (*Aporrectodea trapezoids*) in soil lifted the protein value of the grain of wheat crops (*Triticum aestivum*) by 12% (Baker and Barrett, 1994). Shankar and Sumathi (2008) reported that tomato grown on vermicompost had significantly higher total antioxidants, total carotene, iron (Fe), zinc (Zn), crude fiber and lycopene content than the other organically grown tomatoes. Also tomato, spinach and amaranthus grown on vermicompost had significantly higher vitamin C. Vermicompost applied tomato also registered significantly higher 'shelf-life' when stored at room temperature.

More significantly, *in vitro* studies indicate that organic foods produced by vermicompost can reduce the risks of 'cancer' in humans.

5. Potential of Vermiculture Technologies to Reduce Emissions of Greenhouse Gases (GHGs) in Waste Management Activities and Sequester Carbon into Soil by Use of Vermicompost to Mitigate Global Warming

5.1. Reduction in GHG Emissions in Solid Waste Recycling by Vermicomposting

Waste landfills are proving to be an economic and environmental burden on society. Landfills emit huge and more powerful greenhouse gases methane (CH_4) and nitrous oxides (N_2O) which are molecule to molecule 22 times and 312 times more powerful in absorbing solar radiations than carbon dioxides (CO_2). Every 1 kg of waste diverted from landfills prevents 1 kg of greenhouse gas emission equivalent to CO_2. In 2005, landfill disposal of MSW contributed 17 million tons CO_2-e (equivalent) of GHG in Australia, equivalent to the emissions from 4 million cars or 2.6% of the national GHG emissions. (Australian Greenhouse Office, 2007). Waste management by vermicomposting can divert huge amounts of wastes from landfills.

Studies have established that vermicomposting of wastes by earthworms significantly reduce the total emissions of greenhouse gases in terms of CO_2 equivalent, especially nitrous oxide (N_2O) which is 296-310 times more powerful GHG than CO_2. Our studies showed that on average, vermicomposting systems emitted 463 CO_2-e/m^2/hour respectively. This is significantly much less than the landfill emission which is 3640 CO_2-e /m^2/hour. Vermicomposting emitted minimum of N_2O – 1.17 mg/m^2/hour, as compared to Aerobic Composting (1.48 mg/m^2/hour) and Anaerobic Composting (1.59 mg/m^2/hour). Hence, earthworms can play a good part in the strategy of greenhouse gas reduction and mitigation in the disposal of global MSW (Sinha et al., 2009 b; Chan et al. 2010).

5.2. Reduction in GHGs Emissions in Wastewater Recycling by Vermifiltration

All conventional wastewater treatment systems such as the ‘Activated Sludge’, ‘Aerated Lagoons’ and ‘Rotating Biological Contactors’ etc. are high energy (electricity) requiring processes emitting proportional GHGs. The degradation of ‘organics’ in the wastewater and slurry emits huge amounts of powerful greenhouse gases methane (CH_4) and nitrous oxides (N_2O) and also ammonia (NH_3) which creates foul odor.

Studies done at Rennes University, France on the effects of earthworms on gaseous emissions during vermifiltration of animal wastewater indicates that earthworms decrease the emissions of methane and nitrous oxides and also ammonia. More the population of earthworms in the vermifilter bed lesser is the emissions of these gases (Luth et al., 2011).

5.3. Carbon Sequestration in Soil by Use of Vermicompost in Agriculture and Mitigation of GHGs and Global Warming

Much of the world's carbon is held in the soils, including the farm soils as 'soil organic carbon' (SOC). The global pool of SOC is about 1,550 Pg C (1 Pg= 1,000 million metric tons or MMT) i.e., 41%. The loss of SOC as CO_2 due to aggressive 'ploughing and tillage' in the wake of modern chemical agriculture and mechanized farming practices has augmented the atmospheric carbon pool as greenhouse gas further inducing the global warming and climate change. Of the increase of atmospheric carbon over the last 150 years, about a third (33.3%) is thought to have come from agriculture (Robbins, 2004). Australia has 473 million hectares of agricultural land and emitted 537 million tones of CO_2 in 2009. (Leu, 2011).

All over the world agricultural and environmental scientists are trying to reverse the trend by putting more carbon back into the soil – a process called 'carbon sequestration' through the use of all composts including earthworms vermicompost. Earthworms secrete 'humus' and hence the vermicompost contain more 'stable forms of carbon' as 'humates' which remains in the soil for long periods of time. Compost use in farms would 'sequester' huge amounts of atmospheric carbon (CO_2) and bury them back into the soil, mitigate greenhouse gases and global warming. Composts are in fact disintegrated products of 'plant biomass' which are formed from atmospheric CO_2 fixed during photosynthesis by green plants. Plants absorb atmospheric CO_2 and converts them into 'plant material' (biomass) in sunlight. The Intergovernmental Panel on Climate Change (2000) recognized that carbon (C) sequestration in soils as one of the possible measures through which the greenhouse gas (GHG) emissions and global warming can be mitigated. Applying compost to agricultural lands could increase the amount of carbon (C) stored in these soils and contribute significantly to the reduction of GHG. Application of composts to the soil can lead either to a build-up of soil organic carbon (SOC) over time, or a reduction in the rate at which soil organic matter (SOM) is being depleted from soils – thus benefiting the soil and the environment in every way (Bolan, 2011).

CONCLUSION AND REMARKS

Both biological recycling technologies by earthworms – vermicomposting for solid waste recycling, disinfection and detoxification; and vermifiltration for wastewater recycling and purification can be used as most economical and sustainable alternatives to some of the 'environmentally unfriendly' methods to achieve those objectives of solid waste management and wastewater treatment while also significantly reducing waste and pollution and the emission of green house gases (especially the powerful GHGs – methane and nitrous oxides) mitigating global warming and climate change.

The best part is that the end-products (nutritive vermicompost, treated nutritive water and earthworms biomass) of both waste recycling technologies become very useful resources for agriculture for producing chemical-free, nutritive and health-protective foods for mankind. It is like getting 'gold from garbage' and 'silver from sewage' – converting 'human wastes' into 'brown gold' (vermicompost) and getting 'green gold' (food crops) from brown gold.

Assessing 'Carbon Foot-Print and accounting for the emission of GHGs which induce 'global warming and climate change' has become essential in all modern technologies and developmental activities and all vermiculture technologies show very small 'carbon foot-prints'.

It is also suggestive to recycle all organic wastes first through 'bio-methanation technology' (also called biogas technology) to purposefully generate 'methane' (CH_4) and then vermi-process the 'slurry' generated to obtain more nutritive by-products (vermicompost) for agriculture. This will not only avoid emissions of CH_4 into the environment as greenhouse gas, but also use it as a 'clean burning fuel'. This will be like 'killing several birds with one stone', salvaging human wastes and getting several useful by-products and end-products from them – benefiting both, ecology as well as economy.

Vermiculture is a growing industry all over the world and a 'waste-less' enterprise as all by-products and end products are economically 'useful'. Earthworms not only convert 'Waste into Wealth' but also becomes a valuable asset as 'Worm Biomass' which is finding uses in several industries today. Earthworms are truly justifying the beliefs and fulfilling the dreams of Sir Charles Darwin who called them as '*unheralded soldiers' of mankind*' and '*friends of farmers*' and said that '*there may not be any other creature in world that has played so important a role in the history of life on earth'*.

They are also justifying the beliefs of great Russian scientist Dr. Anatoly Igonin who said '*Nobody and nothing can be compared with earthworms and their positive influence on the whole living Nature. They create soil and improve soil's fertility and provides critical biosphere's functions: disinfecting, neutralizing, protective and productive'*.

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Chapter 11

e-WASTE: SCIENCE, SOCIETY, MANAGEMENT

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ABSTRACT

The modern age is considered as the ‘digital age’; and it is constantly generating wastages;especiallythe electronic waste (*e*-waste). The *e*-waste is a matter of concern and the problem is worldwide. The more we are technologically advanced; there will be more and more *e*-waste generation. The problem related to *e*-waste lies in its properties and nature, because these are some time silent killer. There are some crucial issues related to *e*-waste generation and management and of course related to waste handling. E-waste export remains a dirty little secret of the high-tech revolution. All over the world, *e*-waste is of importance because it has it’s own ‘life cycle’ through waste-economy-society path. The present chapter is a review on someless talking issues related to electronic wastes, the *e*-waste.

Keywords: *e*-waste, digital age, environmental hazards, health issues

INTRODUCTION

Science and technology advancement led the way to increase electronic gadgets. Revolution in information and communication technology has enhanced the lifestyle of human that has been noticed through massive change in our economies, industries, institutions and the way we led or organize our lives. At present electronics industries compete forthe largest and fastest growth in manufacturing thegadgets (Radha, 2002; DIT, 2003). However, enormous change and large scale development in modern times have remarkably enhanced the quality of our life and living. Not only economic growth, availability of electronic goods in recent market has lead consumers to replace their households with new models forwarding the growing piles of *e*-waste.

Science and technology advancement proves to be worthwhile in ourlives,on other hand it is jeopardy. The electronic goods after certain times become non-productive and are finally designated as 'wastes'. These wastes certainly led to serious problem and its effects are manifold.

Sometimes these wastes are hazardous and other wastes generated through electronics pose threat to human health and environment. Proper management of wastes is one of the major concerns now-a-days where electronics has disadvantages. So management of electronic wastes being a challenge to modern societies; it is required to be more coordinated for addressing the issues related to aforesaid problem to achieve sustainabledevelopment.

SCIENCE

e-Waste:What Is It?

According to the Basel Convention,1989, wastes are substances or objects, which are disposed of or are intended to be disposed of, or are required to be disposed of by the provisions of national laws.

Any substance that is not used as resource in our lives are known as wastes, it may be natural resource or manufactured goods of our daily use. Similarly, electronics/electrical goods that are not fit for their originally intended use or have reached their end of life are designated as electronic waste (*e*-waste). E-waste includes computers, mainframes, servers, monitors, CDs, printers, scanners, copier, calculators, fax machines, battery cells, cellular phones, transceivers, TVs, medical apparatus and electronic components besides white goods viz. refrigerators and air conditioners many of which contains toxic materials (Lalchandani 2010).

e-waste is of immediate and long term concern for environmentalists as it may lead to unforeseen health hazards in human, and may cause several environmental problems. On the same hand, *e*-waste contains valuable materials like copper, silver, gold and platinum which could be processed for their recovery.

According to European Union, the stream of e-waste comes from 'Waste Electrical and Electronic Equipment' (WEEE). The EEE has been further classified into 'components', 'sub-assemblies' and 'consumables'(Jain, 2008). As there is no definition of the WEEE in the environmental regulations in India, it is simply called '*e*-waste'.

e-waste or electronic waste, therefore, broadly described as loosely discarded, surplus, obsolete, broken, electrical or electronic devices.

Figure 1. *e*-waste in a waste dump in Kolkata, p.c-author's own collection.

e-Waste: Composition

e-waste is composed of discarded electronics, its composition is highly diverse and differs according to products. It falls under hazardous and non-hazardous categories. Broadly, it consists of ferrous and non-ferrous metals, plastics, glass, wood and plywood, printed circuit boards, concrete, ceramics, rubber and other items. Iron and steel constitute about 50% of the waste, followed by plastics (21%), and 13% non-ferrous metals (like copper, aluminium, precious metals like silver, gold, platinum, palladium etc.) and other constituents (Lalchandani, 2010). One photograph of *e*-waste pile in one waste dumping ground in Kolkata has been taken as example, Figure 1. Widmer et al. (2005) calculated *e*-waste composition variations like, iron, copper, aluminium, gold and other metals- is over 60%,plastics account for about 30% and hazardous pollutants comprise about 2.70%. But *e*-waste is not just poisonous: it contains precious metals, too. Processors, chips and connecting pins (known as "gold fingers") contain seams of silver, gold and palladium; these "deposits" are 40 to 50 times richer than dug-up ores, according to a study conducted by the United Nations University. Other less valuable and more troubling loads for the "urban miners" include cadmium, lead and mercury.

Presence of elements like lead, mercury, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants beyond threshold quantities make e-waste hazardous. On burning at low temperatures, additional toxins viz.halogenated dioxins and furans are created. Many of these toxic constituents are elements, which never disappear, though may change in form, andaccumulate in to food chain of biospherecausing serious pollution (BAN, 2002). Along with communities and the global ecosystem, these toxins are of risk to electronics recycling workers around the world if not disposed carefully. While some naturally occurring substances are harmless in nature, their use in the manufacture of electronic equipment often make hazardous substances (e.g., chromium becomes chromium VI). The following list gives a selection of the mostly found toxic substances in *e*-waste.

- PCB (polychlorinated biphenyls) ← condensers, transformers,
- Chlorofluorocarbon (CFC) ← cooling unit, insulation foam,
- PVC (polyvinyl chloride) ← cable insulation,
- Arsenic ← small quantities in the form of gallium arsenide in light emitting diodes,
- Barium ← getters in CRT,
- Beryllium ← power supply boxes containing silicon controlled rectifiers and x-ray lenses,
- Cadmium ← rechargeable NiCd-batteries, fluorescent layer (CRT screens), printer inks and toners, photocopying-machines (printer drums),
- Chromium VI ← data tapes, floppy-disks,
- Lead ← CRT screens, batteries, printed wiring boards,
- Lithium ← Li-batteries,
- Mercury ← fluorescent lamps that provide backlighting in LCDs, in some alkaline batteries and mercury wetted switches,
- Nickel ← rechargeable NiCd-batteries or NiMH-batteries, electron gun in CRT,
- Rare Earth elements (Yttrium, Europium) ← fluorescent layer (CRT-screen),
- Selenium ← old photocopying-machines (photo drums),
- Toner Dust ← toner cartridges for laser printers/copiers,
- Americium ← medical equipment, fire detectors, active sensing element in smoke detectors,

So, the main constituent in the e-wastes are some chemical components, directly or indirectly causing harm to human health,heavy metals, rare earth elements, and some time cancer causing, sometime leading to environmental problems like ozone hole depletion etc. (BAN, 2002)

e-Waste: Impact

The *e*-waste components and their potential environmental hazards can be summarized as:

- Cathode ray tubes (used in TVs, computer monitors, ATM, video cameras, and more): lead, barium, other heavy metals leaching into the ground water;
- Printed circuit board (a thin plate on which chips and other electronic components are placed): air emissions, discharge into rivers of glass dust, tin, lead, brominated dioxin, beryllium cadmium, and mercury;
- Chips and other gold plated components: hydrocarbons, heavy metals, brominated substances discharged directly into rivers causing acidificationtin and lead contamination of surface and groundwater, air emissions of brominated dioxins, heavy metals and hydrocarbons;

- Plastics from printers, keyboards, monitors, etc.: emissions of brominated dioxins, heavy metals and hydrocarbons
- Computer wires: hydrocarbon ashes released into air, water and soil.

SOCIETY

e-Waste: Global

Waste consisting of dead electronic goods, or *e*-waste, is growing at three times the rate of other kinds of rubbish, fuelled by gadgets' diminishing lifespan and the appetite for consumer electronics among the developing world's up-and-coming middle classes. More than 50 MT *e*-waste is generated globally every year, as part of municipal wastes (Schwarzer et al. 2005). A United Nations based report predicted that by 2020, *e*-waste from old computers would jump by 400 per centthan 2007 levels in China and by 500 per cent in India. Additionally, *e*-waste fromdiscarded mobile phones would be about seven times higher than2007 levels in China, 18 times higher in India by 2020 (Young 2010). The Basel Action Network (BAN), working for prevention of globalization of toxic chemicals, reported that 50 to 80 per cent of *e*-waste collected in the US is exported to India, China, Pakistan, Taiwan and a number of African countries.

China produces about 2.3 million tonnes of *e*-waste domestically, second to the U.S (about three million tons) (Lalchandani,2010). The EU and the U.S. would account for maximume-waste generation during this current decade. As per the Inventory Assessment Manual of the UNEP, 2007, it was estimated that the total *e*-waste generated in the EU is about 14-15 kg per capita or 5-7 MT per annum. The *e*-waste generation in the EU is expected to grow at the rate of 3-5% per year. In the past, *e*-waste had increased by16-28% every five years which is three times faster than average annual municipal solid waste generation. In the U.S., *e*-waste accounts for 1-3%of the total municipal waste generation as the United States Environmental Protection Agency (USEPA) reported 2.6 MT of *e*-waste in 2005, accounted for 1.4% of total wastes (Lalchandani,2010). A 2011 report by Pike Research, a consultancy, estimates that the volume and weight of global *e*-scrap will more than double in the next 15 years.

e-Waste: India

In India several independent studies by different organizations documentd about the *e*-waste issues. It has been estimated that 4 lakh tonnes of *e*-waste, about 7.2 MT industrial hazardous waste, 1.5 MT of plastic waste, 1.7 MT of medical waste, 48 MT of municipal waste is generated in India annually (Agarwal 2010). In India annual *e*-waste generation per capita is less than 1kg (RajyaSabha report, 2010). In 2005, the Central Pollution Control Board (CPCB) estimated India's *e*-waste at 1.47 lakh tonnes or 0.573 MT per day (LokSabha report, 2010). 70% of total *e*-waste is contributed by 10 states in the country while 65 cities generate more than 60% of *e*-waste in India. Maharashtra stands first in generating *e*-waste followed by Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab among the Indian states. *e*-waste generation among the top ten cities follows the pattern as Mumbai> Delhi>Bengaluru> Chennai> Kolkata> Ahmedabad> Hyderabad> Pune>Surat> Nagpur (RajyaSabha report, 2008).

The main sources of *e*-waste in India are the government, public and private (industrial) sectors, accounting for almost 70% of total waste generation. An Indian market Research Bureau(IMRB) survey of '*e*-waste generation at Source' in 2009 found that out of the total *e*-waste volume in India, televisions and desktops including servers comprised 68% and 27% respectively. Imports and mobile phones comprised of 2% and 1% respectively. The Ministry of Environment and Forests (MoEF) has notified the Hazardous Wastes (Management, Handling and Transboundary Movement) Rules, 2008 for effective management of hazardous wastes, including *e*-waste in the country. In India, recycling of *e*-waste is almost entirely left to the informal sector, which does not have adequate means to handle either the increasing quantities or certain processes, leading to intolerable risk for human health and the environment.

e-Waste: Issue Beyond Local or Global

Dumping electronic waste onto the developing world is a hazardous but profitable business.

POOR countries have long been a popular destination for the rich world's toxic trash. In 1987 an Italian importer sparked international outrage by dumping 8,000 leaky barrels in the Nigerian village of Koko; Nigeria fined importers $1m for trying to bring in two 12-metre containers full of defunct televisions, computers, microwaves and stereos, aboard a ship. Every year, upgradation of their TVs, cell phones, computers and other electronic devices at a breathtaking paceproduces 300 million tons of electronic waste annually as the reported by The Environmental Protection Agency.

***Disposing of e-waste** legally and responsibly has been a political and a practical headache for years. And a growing appetite for consumerism around the world is only fueling the problem (CBS News).*

Basel Convention, (Basel, Switzerland, 1989) was the first international law to regulate the flow of hazardous waste from industrialized nations (members of the Organization for Economic Co-operation and Development or OECD) to developing ones for disposal. In an amendment to the treaty in 1995 it aimed to stop the rich world dumping its harmful detritus in poor countries. The Basel signatories took the step in October, 2011 towards a general ban on the export of hazardous waste including electronic scrap. But poorer countries already produce a quarter of the world's *e*-waste pile; they could overtake rich ones as early as 2018.

Under the terms of the Basel Ban, industrialized nations like Japan, Taiwan, South Korea, and the 27 members of the European Union (in other words, many of the world's largest consumer economies) require their manufacturers to provide takeback programs for all electronic products they produce (BAN). Europe was the first to ban a number of toxic substances used to manufacture electronics to cut the toxic stream at source. High tech recyclers such as Umicore in Belgium and Xstrata in Canada can recover up to 95% of the metal using furnaces and solvents. In the Guiyu areas of southern China 100,000 people work in *e*-waste recycling; is "ground zero for the *e*-waste trade (BAN). Standard practice is to separate the plastic by boiling circuit boards on stoves, and then leach the metals with acid;

the result is workers' risk fromthe burns, inhaling fumes and poisoning from lead and other carcinogens, even high miscarriage rates in local women.

EPA got criticism failing to hold back some of the *e*-waste recycling industry's dirtiest practices. Currently, cathode ray tubes (CRTs), with their high lead content, are the only electronics banned for export by the U.S. for recycling overseas, other electronics flow virtually unrestricted. The EPA lacking in regulation enforcement. House Foreign Affairs Committee reported in August 2008, that large amounts of *e*-waste collected in the United States were still ending up in China and India, and often dismantled in the worst environmental and health condition. Apart from these, one big dismantled zone is Taiwan's "processing zone." Electronic wastes are imported into Ghana from European and North American countries, There is a new trend where brand new EEE is also imported from Asia, mainly China and UAE (Dubai) (UNEP, 2011).

Recycling *e*-trash remains a lucrative business for poor nations and a convenience for rich ones, in spite of of the toxic legacy.

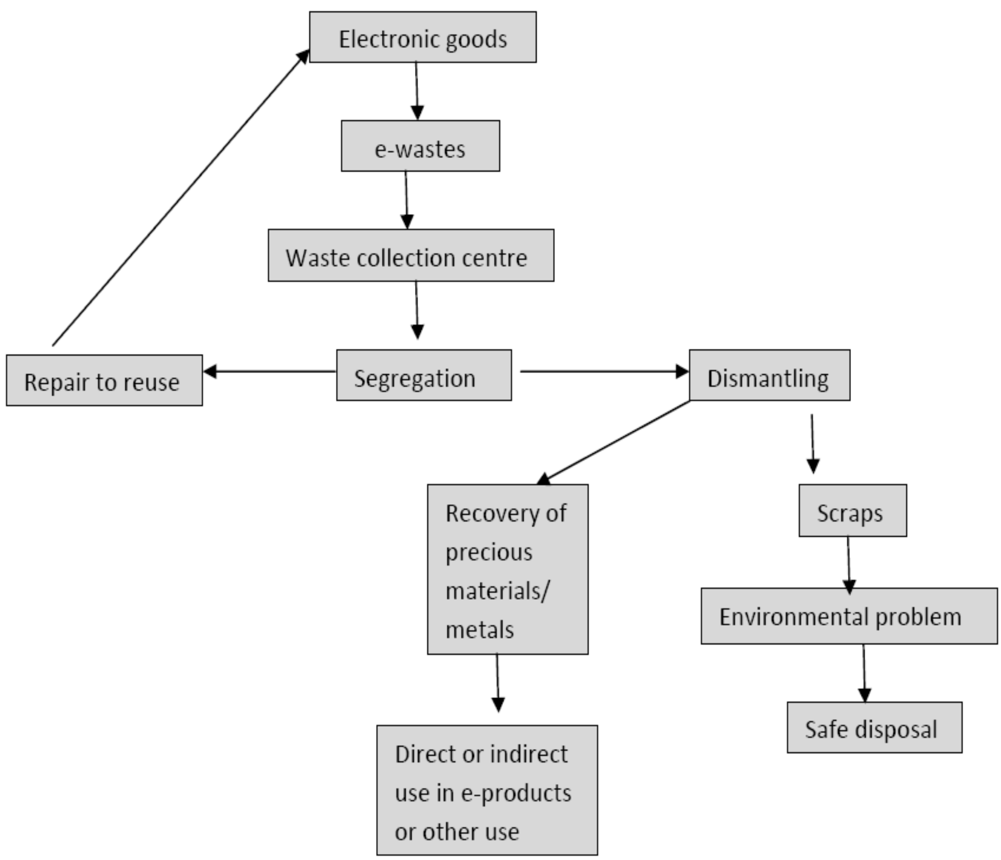

Figure 2. *e*-waste: Science, Society, Management, a schematic diagram of interrelationship of *e*-wastes, and socioeconomic components.

MANAGEMENT

e-Waste: Management

New electronic products have become an integral part of our daily lives providing us with more comfort, security, easy and faster acquisition and exchange of information; leading tounrestrained resource consumption and an alarming rate of waste generation. Both developed countries and developing countries like India face the problem of *e*-waste management. The countries of the European Union (EU) and other developed countries to an extent have addressed the issue of *e*-waste by taking policy initiatives and by adopting scientific methods of recycling and disposal of such waste.

Reusing and recycling are the other ways of dealing with *e*-wastes. They have been preferable because they increase the lifespan of the products and produce less waste over time. Re-usemay be direct secondtime use, or use after slight modifications are made to the originalequipment like memory upgrades, etc. However, they end up as waste eventually as they have limited life span. The reuse of second-hand electronic goods in the developing world including India falls in this category, where the waste ends up locally and where there is no adequate facility and competence to deal with them appropriately.

The major components of *e*-waste management are:

1. *e*-waste collection → sorting → transportation
2. *e*-waste recycling, recovery of valuable resource, sale (export) of dismantled parts for precious metal recovery.

And the noteworthy to mention about the stakeholders take part in *e*-waste management:

Manufacturers' → Users → Recyclers →Policy makers

The main and profitable ways of *e*-waste management is to recycle the waste as much possible, which will lead to no loss of resources. For recycling, the process comprises mainly three steps:

Detoxification- removal of critical components (e.g., lead glass from CRT screens, CFC gases from refrigerators, light bulbs and batteries etc.) to avoid dilution of and or contamination with toxic substances during the downstream processes. *Shredding*- normally an industrial large scale operation to obtain concentrates of recycleable materials in a dedicated fraction and also to further separate hazardous materials. The gas emissions are filtered and effluents are treated to minimize environmental impact.

Refining- of resources in *e*-waste is possible with technical solutions to get back raw materials with minimal environmental impact. The fractions refined or conditioned are sold as secondary raw materials or to be disposed of in a final disposal site(s).

e-Waste: Challenges for Management

- Certainly there is no well documentation about generation of *e*-waste amount although it is rapidly increasing domestically and by imports,
- There is almost no awareness among manufacturers and consumers about the hazards of incorrect *e*-waste disposal, especially in the developing nations,
- No accurate estimates of the quantity of *e*-waste generated and recycled available in the country like India, because major portion is processed under the informal sector using rudimentary techniques (e.g., acid leaching, open-air burning) leading to severe environmental damage,
- Lack and absence of knowledge of 'toxins' in *e*-wastes among the workers, leading to ready exposure to health hazards,
- Inefficient recycling knowledge results in losses of material value and resources,
- No stricter legislation for handling of *e*-waste at present, in the country like India, and as a cause lack of designated authority to ensure transparency, audit and inspect the *e*-waste generating sectors, to examine the authorization of generation and or recycling, etc.

Apart from the above issues and challenges for proper handling and management of e-wastes, there are some problems under the problem; the existing e-waste management practices. Mainly in the south-east Asian countries, the process of certain e-waste management practices leads to generation of some more critical problems for the human and or for environment. The process and the problems are summarized in short:

***Incineration*-** destroying waste through burning. Because of the variety of substances in *e*-waste, incineration is a major risk of generating and dispersing contaminants and toxic substances. The gases released during burning and the residue ash is often toxic and the process is at risk at without prior treatment and or sophisticated flue gas purification. There happens loss of valuable trace elements which could have been recovered had they been sorted and processed separately.

Open burning **-** burning at low temperatures, release more pollutants than a controlled incineration process at any MSW-plant. Inhalation of open fire emissions can trigger asthma attacks, respiratory infections, and cause other problems such as coughing, wheezing, chest pain, and eye irritation. Chronic exposure to open fire emissions may lead to diseases like emphysema and cancer, as burning PVC releases hydrogen chloride,on inhalation it mixes with water in the lungsforming hydrochloric acidleading to corrosion of the lung tissues, and other respiratory complications. Often open fires burning with less oxygen, form carbon monoxide, poisonous to the blood when inhaled. The residual particulate matter in the form of ash is prone to fly aroundand can also be dangerousupon inhalation.

Landfilling - most widely used methods of waste disposal. Landfill leakage is very common and the leachate often contains heavy metals and other toxic substances able to contaminate soil and water resources. Older landfill sites and uncontrolled dumps are at higher risk of releasing hazardous emissions. Mercury, Cadmium, Lead are among the most toxic leachates. Vaporization is also of concern in landfills for the volatile compounds (e.g., mercury and its modifications).

Significant impacts from landfilling could be avoided by conditioning hazardous materials from *e*-waste and by filling landsonly with those fractions which are no further recycleable. *e*-waste: best practices for management.

Globally the main *e*-waste generator sectors are: Corporate consumers (service sector, industrial sector) and Institutional consumers (health sector, educational sector). The best option for dealing with *e*-waste is to reduce the volume. Designers should ensure that the product is built for re-use, repair and/or upgradeability. Stress should be laid on use of less toxic, easily recoverable and recyclable materials which can be taken back for further long term use, remanufacturing, disassembly and reuse. Recycling and reuse of material are the next level of potential options to reduce *e*-waste (Ramachandra and Saira, 2004). Recovery of metals, plastic, glass and other materials reduces the magnitude of *e*-waste. These options have a potential to conserve the energy and keep the environment free of toxic material that would otherwise have been released. A schematic diagram of *e*-waste management path way, and the interrelationship of waste-economy-society is described in Fig.2.

The manufactures, consumers, regulators, municipal authorities, governments, and policy makers need super co-ordination to take the matter seriously in an integrated manner. It is the need for every government to have an "*e*-waste-policy" and some stricter rules. Sustainability of *e*-waste management systems has to be ensured by improving the effectiveness of collection and recycling systems (e.g., publicprivatepartnerships (p-p-p model) in setting up buy-back or drop off centers and facilitating every recycling possibilities.

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