GUIDELINES ON ENVIRONMENTALLY SOUND CO-PROCESSING OF SCHEDULED WASTES IN CEMENT INDUSTRY

DEPARTMENT OF ENVIRONMENT MALAYSIA

GUIDELINES ON
ENVIRONMENTALLY SOUND
CO-PROCESSING OF SCHEDULED WASTES IN CEMENT INDUSTRY

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FOREWORD

Guidelines on Environmentally Sound Co-Processing of Scheduled Wastes in Cement Industry was developed in line with new technology development and current practice in the waste management hierarchy based on 'cradle to cradle' principle. Management of wastes has risen into a new dimension by taking the approach of promoting the use of waste whenever possible, as alternative raw materials or alternative fuels to substitute the raw materials, without compromising the quality of products. Indirectly, it will eliminate the need for waste disposal to landfill.

Co-processing is a method that uses scheduled wastes as raw material or as a source of energy or both to replace natural mineral resources and fossil fuels in cement production.

It is hoped that the publication of this guideline will increase the understanding of the industries, especially the cement industry which aims to make scheduled wastes as alternative raw materials, alternative fuel or cement additives in the production of cement product and comply with the requirements of the Environmental Quality Act 1974

Dato' Halimah Hassan

Director General

Department of Environment

Ministry of Natural Resources and Environment

25 May 2015

GUIDELINES ON ENVIRONMENTALLY SOUND CO-PROCESSING OF SCHEDULED WASTES IN CEMENT INDUSTRY

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1.0 INTRODUCTION

1.1 Management of scheduled wastes in Malaysia has been implemented based on the cradle to grave principle. However, in line with the development of new technology and current practice in the waste management hierarchy which promote reuse or recycling or reutilization of waste, a transformation in the waste management to another process-integrated technology, advocated as cradle to cradle approach has emerged. This approach promotes the use of waste whenever possible, as alternative raw material or alternative fuel to substitute the raw material, without jeopardizing the quality of the same product. This will subsequently eliminate the need for waste disposal to landfills.

1.2 Shifting attitudes and better understanding from all stakeholders with regards to the importance of conserving the natural resource and pollution prevention to protect the environment, this waste to wealth practice has shown an increasing trend globally, as well as in Malaysia. Nowadays, industries in Malaysia have shown their interest to choose the disposal of waste to landfills as the last option, by sending the scheduled waste to recovery facilities to recover the valuable components, as well as to be co-processed in cement industries as alternative raw material and cement additives.

1.3 Co-processing is the use of scheduled waste as a raw material or as a source of energy or both as an alternative to natural mineral resources and fossil fuel in cement production.

1.4 Co-processing of wastes in properly controlled cement kilns provides energy and materials recovery while cement is being produced, offering an environmentally sound recovery option for many waste materials. Properly controlled co-processing can provide a practical, cost-effective and environmentally preferred option to landfill and incineration. In general, co-processing of waste in resource-intensive processes can be an important element in a more sustainable system of managing raw materials and energy.

1.5 Scheduled wastes to be used as alternative raw material or alternative fuel or additives in cement industries have certain components or characteristics that make them suitable for such purpose. Examples of scheduled waste which has been approved by Department of Environment to be co-processed by cement plant in Malaysia are as in **Table 1**:

Purpose of co-processing	Waste code under First Schedule, Environmental Quality (Scheduled Waste) Regulations 2005	Type of waste
Alternative raw material	SW 104	Used copper slag Used garnets Spent pot linings

	SW 204	Sludges containing one or several metals including chromium, copper, nickel, zinc, lead, cadmium, aluminium, tin, vanadium and beryllium
	SW 207	Sludges containing flouride
Cement additive	SW 104	Fly ash from coal-based powerplant
	SW 205	FGD gypsum from power plant (i.e. not necessary be coal based) Gypsum from chemical plant

Table 1: Examples of scheduled wastes approved for co-processed in cement industry

2.0 SCOPE

These guidelines are prepared to promote and facilitate the cement industry to plan and implement co-processing activities in their plant in an environmentally sound manner, without jeopardising the quality of cement.

3.0 OBJECTIVE

These guidelines are prepared as a guidance document for cement plants who intend to use scheduled wastes as alternative raw material and/or alternative fuel and/or cement additive in the production of cement product, in an environmentally sound manner.

These guidelines will also:

(a) Promote waste-to-wealth concept.

(b) Outline the legal requirement and procedure to implement co-processing activity in cement plant.

(c) Ensure the implementation of co-processing activity in cement plant is in compliance with Environmental Quality Act 1974 and all Regulations, Order and Rules under the Act.

4.0 DEFINITION

For the purpose of these guidelines, the definitions of terms used are as follows:

Aggregates	Particulate materials used in construction such as sand, gravel, crushed stone and crushed slag
Alkali bypass	A duct located between the feed end of the kiln and the preheater tower. A portion of the kiln exit gas is withdrawn through this and quickly cooled by air or water to avoid excessive alkali, chloride and sulphur build-up on the raw feed. This is also known as kiln exhaust gas bypass.
Alternative fuels and raw materials (AFR)	Inputs to clinker production derived from waste streams that contribute energy and/or raw material.
Alternative fuels	Wastes with recoverable energy value, used as fuels in a cement kiln, replacing a portion of conventional fossil fuels such as coal. Other terms include: secondary, substitute or waste derived fuels.
Alternative raw materials	Waste materials containing useable minerals such as calcium, silica, alumina and iron, which can be used in the kiln to replace raw materials such as clay, shale and limestone. Also known as secondary or substitute raw materials.
Best available techniques (BAT)	The most effective methods of reducing emissions and the impact on the environment as a whole.
Bypass dust	Dust discarded from the bypass systems of the suspension preheater, precalciner and grate preheater kilns, consisting of fully calcined, kiln feed material.
Calcination	Heat-induced removal, or loss of chemically-bound volatiles other than water. In cement manufacture this is the thermal decomposition of calcite (calcium carbonate) and other carbonate minerals that gives a metallic oxide (mainly CaO) plus carbon dioxide.
Cement kiln dust (CKD)	The fine-grained, solid, highly alkaline material removed from cement kiln exhaust gas by air pollution control devices. Much of the CKD material is unreacted raw material, including raw mix at various stages of burning and particles of clinker. The term can be used to denote any dust from cement kilns, such as that coming from bypass systems.

Cement
Finely ground inorganic material that, when mixed with water, forms a paste that sets and hardens by means of hydration reactions and processes and that, after hardening, retains its strength and stability under water.

Cement additive
Substances added to impart or improve desirable properties or suppress undesirable properties of the cement.

Clinkering
The thermo-chemical formation of clinker minerals, especially to those reactions occurring above about 1,300° C; also the zone in the kiln where this occurs. Also known as sintering or burning.

Co-processing
The use of suitable waste materials in manufacturing processes for the purpose of energy and/or resource recovery and resultant reduction in the use of conventional fuels and/or raw materials through substitution.

Destruction and removal efficiency (DRE)
Efficiency in destruction and removal of a given organic compound. Mathematically, DRE is calculated as follows:

DRE = [(*W*in – *W*out stack)/*W*in] × 100

where *W*in is the mass feed rate of one principal organic hazardous constituent (POHC) in the waste stream fed to the kiln, and *W*out stack is the mass emission rate of the same POHC in the exhaust emissions prior to release to the atmosphere.

Destruction efficiency (DE):
A measure of the percentage of a given organic compound that is destroyed by the combustion process.

Mathematically, DE is calculated as follows:

DE = [(*W*in – *W*out combustion chamber)/*W*in] × 100

where *W*in is the mass feed rate of one principal organic hazardous constituent (POHC) in the waste stream fed to the kiln, and *W*out combustion chamber is the mass emission rate of the same POHC leaving the kiln (upstream of all air pollution control equipment).

The DE represents the fraction of the organics entering a kiln, which is actually destroyed; the DRE represents the fraction of the organics entering a kiln and emitted from the stack to the atmosphere

Dry process
Process technology for cement production. In the dry process, the raw materials enter the cement kiln in a dry condition after being ground to a fine powder called the raw meal. The dry process consumes less energy than the wet process, where water is added to the raw materials during grinding to form

	slurry.
Emissions testing	Manual collection of stack gas samples, followed by chemical analysis to determine pollutant concentrations.
Heating (calorific) value	The heat per unit mass produced by complete combustion of a given substance. Calorific values are used to express the energy values of fuels, usually expressed in megajoules per kilogram (MJ/kg).
Kiln line	The part of the cement plant that manufactures clinker; comprises the kiln itself, any preheaters and precalciners and the clinker cooler apparatus.
Kiln	The heating apparatus in a cement plant for manufacturing clinker. Unless otherwise specified, it may be assumed to refer to a rotary kiln.
Precalciner	A kiln line apparatus, usually combined with a preheater, in which partial to almost complete calcination of carbonate minerals is achieved ahead of the kiln itself, and which makes use of a separate heat source. A precalciner reduces fuel consumption in the kiln, and allows the kiln to be shorter, as it no longer has to perform the full calcination function.
Preheater	An apparatus for heating the raw mix before it reaches the dry kiln itself. In modern dry kilns, the preheater is commonly combined with a precalciner. Preheaters use hot exit gases from the kiln as their heat source.
Pre-processing	Alternative fuels and/or raw materials not having uniform characteristics must be prepared from different waste streams before being used as such in a cement plant. The preparation process, or pre-processing, is needed to produce a waste stream that complies with the technical and administrative specifications of cement production and to guarantee that environmental standards are met.
Raw mix/meal/feed	The crushed, ground, proportioned, and thoroughly mixed raw material-feed to the kiln line.
Recovery	Any operation where waste is serving a useful purpose by replacing other materials that would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy.
Rotary kiln	A kiln consisting of a gently inclined, rotating steel tube lined with refractory brick. The kiln is fed with raw materials at its upper end and heated by flame from, mainly, the lower end, which is also the exit end for the product (clinker).

Trial burn	Emissions testing performed for demonstrating compliance with the destruction and removal efficiency (DRE) and destruction efficiency (DE) performance standards and regulatory emission limits; is used as the basis for establishing allowable operating limits.

5.0 OVERVIEW OF CEMENT MANUFACTURING

5.1 The crucial constituent in concrete is cement. It is a non-metallic, inorganic fine powder, which will forms into paste, set and harden when mixed with water.

5.2 Cement production involves the heating, calcining and sintering of an accurate mix of calcareous and argillaceous materials, usually limestone and clay. This produces cement clinker, which is then cooled and ground with additives such as gypsum to make cement.

5.3 The most widely used production process is for Portland cement clinker, described in more detail in **Annex 1** of these guidelines.

5.4 Cement manufacturing is a resource intensive industry. It require about 1.5–1.7 tonnes of quarried raw material to produce a tonne of clinker, and the cement kilns require substantial energy with temperatures of over 2,000° C . Each tonne of cement produced typically requires 60–130 kilograms of fuel oil, or its equivalent, and about 105 KWh of electricity (Loréa, 2007). On average, energy costs of fuel and electricity represent 40 per cent of cement manufacturing costs (EIPPCB, 2010).

5.5 Clinker burning is the most important phase of the production process in terms of the environmental impact associated with cement manufacture. Depending on the specific production processes, cement plants cause emissions to air and waste emissions to land such as cement kiln dust (CKD). Other impacts to the environment are discharge to water, noise and odour pollution.

5.6 The pollutants released to air are particulates, nitrogen oxides (NO_X) and sulphur dioxide (SO_2), carbon oxides (CO, CO_2), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCCDs/PCDFs), volatile organic compounds (VOC), metals and their compounds, hydrogen chloride (HCl) and hydrogen fluoride (HF). The type and quantity of air emissions depend on varying parameters, for example, the raw materials and fuels used and the type of process.

5.7 Cement manufacturing is also associated with impacts of resource extraction (fossil fuel, limestone and other minerals) upon environmental quality, biodiversity, landscape aesthetics and the depletion of non-renewable or slowly renewable resources, such as fossil fuels or groundwater (Battelle, 2002).

5.8 **Figure 1** illustrates the general overview of cement manufacturing process.

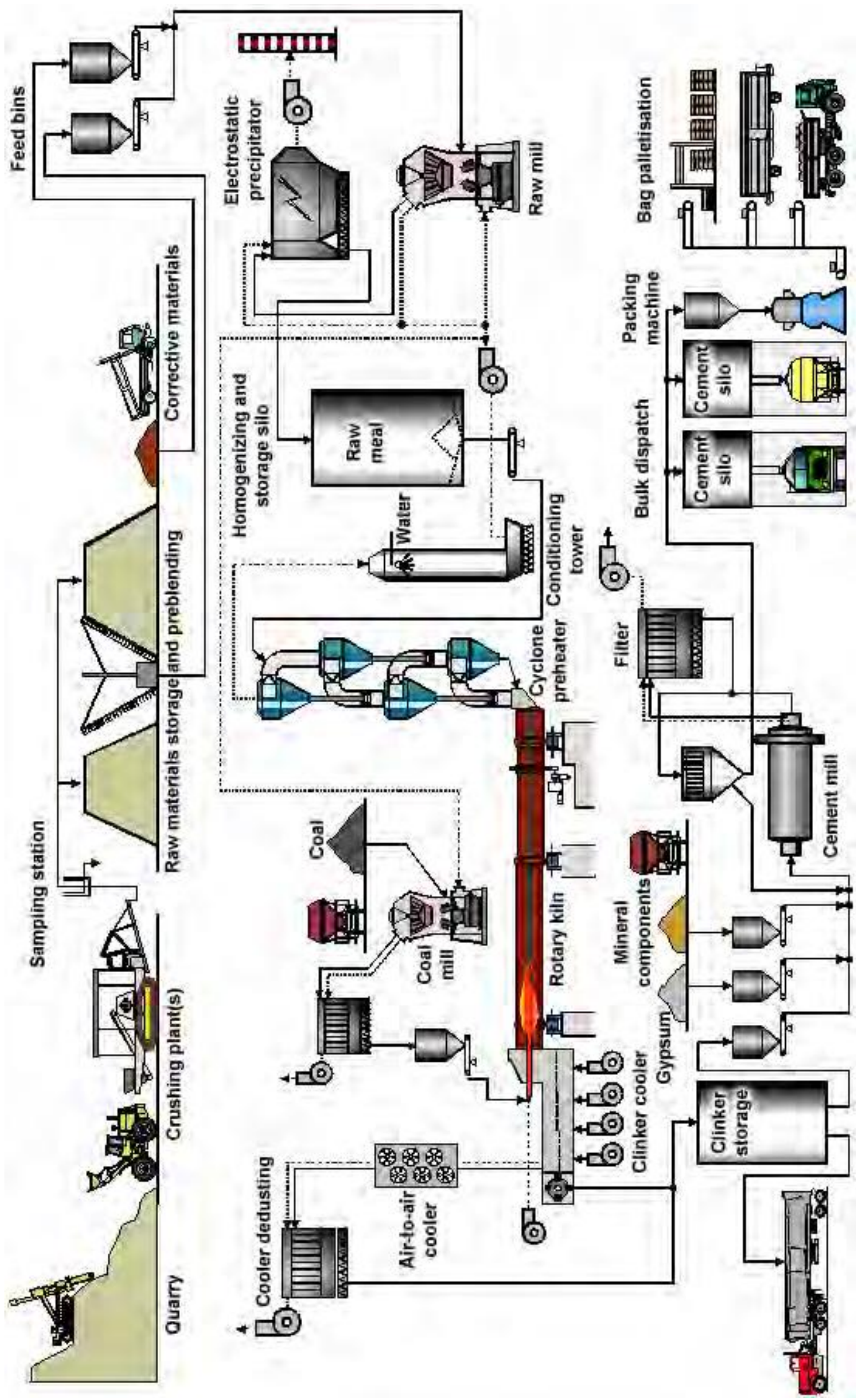


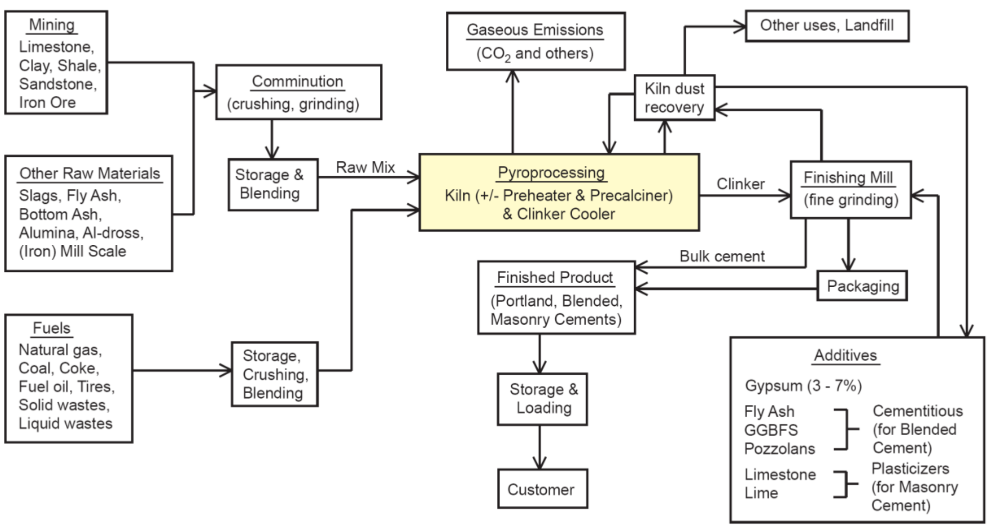
Figure 1: General overview of a cement manufacturing process
Source: CEMBUREAU (2006)

6.0 CO-PROCESSING OF SCHEDULED WASTE IN CEMENT KILNS

6.1 Overview

6.1.1 Co-processing involves the use of waste in manufacturing processes for the purpose of energy and resource recovery by substituting or reducing the use of conventional fuels and raw materials. In particular, the co-processing of scheduled waste in cement kilns allows the recovery of the energy and mineral value from waste while cement is being produced. Co-processing wastes serve a useful purpose in replacing materials that would have otherwise been used in cement manufacturing, thereby conserving natural resources. **Figure 2** provides a process flow diagram of the general cement manufacturing process

Figure 2 – Flow diagram of the general cement manufacturing process



Source: van Oss (2005)

Note:

1. *Fly ash used as other raw material referred to fly ash from incinerators, emission control equipments and etc. that fulfilled the Waste Acceptance Criteria for alternative raw material.*
2. *Fly ash used as additive referred to fly ash coal-based power plant that fulfilled the Waste Acceptance Criteria for cement additive.*

6.1.2 Cement manufacture generally can consume significant quantities of wastes as fuel and alternative raw materials. This consumption reflects the process characteristics in clinker kilns, which ensure the complete breakdown of the raw materials into their component oxides and the recombination of the oxides into the clinker minerals. The essential process characteristics for the use of hazardous and other wastes, fed to the kiln via appropriate feed points, can be summarized as follows (EIPPCB, 2010):

(a) Maximum temperatures of approximately 2,000° C (main firing system, flame temperature) in rotary kilns;

(b) Gas retention times of about 8 seconds at temperatures above 1,200° C in rotary kilns;

(c) Material temperatures of about 1,450° C in the sintering zone of rotary kilns;

(d) Oxidising gas atmosphere in rotary kilns;

(e) Gas retention time in the secondary firing system of more than 2 seconds at temperatures above 850° C; in the pre-calciner, the retention times are correspondingly longer and temperatures are higher;

(f) Solids temperatures of 850° C in the secondary firing system and/or the calciner;

(g) Uniform burnout conditions for load fluctuations due to the high temperatures at sufficiently long retention times;Destruction of organic pollutants because of high temperatures at sufficiently long retention times;

(h) Sorption of gaseous components such as HF, HCl, and SO_2 on alkaline reactants;

(i) High retention capacity for particle-bound heavy metals;\

(j) Short retention times of exhaust gases in the temperature range known to lead to formation of PCDDs/PCDFs;

(k) Simultaneous material recycling and energy recovery through the complete use of fuel ashes as clinker components;

(l) Product-specific wastes are not generated due to a complete material use into the clinker matrix (although some cement plants dispose of CKD or bypass dust);

(m) Chemical-mineralogical incorporation of non-volatile heavy metals into the clinker matrix.

6.1.3 Potential benefits possible through the use of hazardous and other wastes in cement manufacturing are the recovery of the energy content of waste, conservation of non-renewable fossil fuels and natural resources, reduction of CO_2 emissions, reduction in production costs, and use of an existing technology to treat hazardous wastes (see, for example, Mantus, 1992; Battelle, 2002; WBCSD, 2005; Karstensen, 2007b).

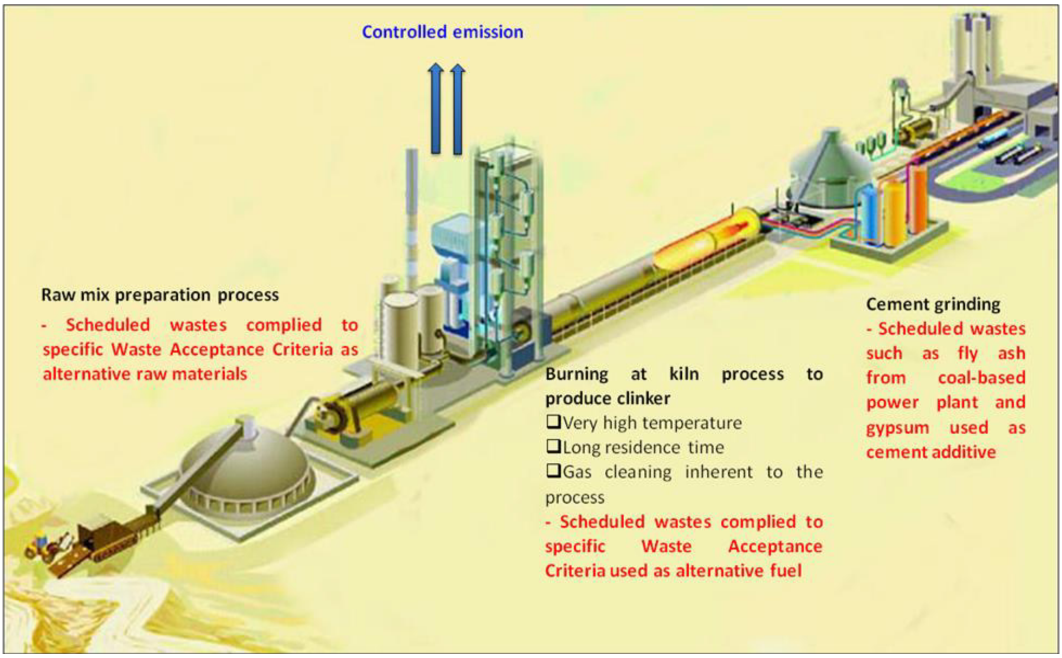
6.1.4 Co-processing of scheduled wastes in cement kilns shall be carried out only according to best available techniques (BAT) while meeting requirements set out for input, process and emission. **Table 2** outlined the general principles for co-processing of scheduled wastes and other wastes in cement kilns.

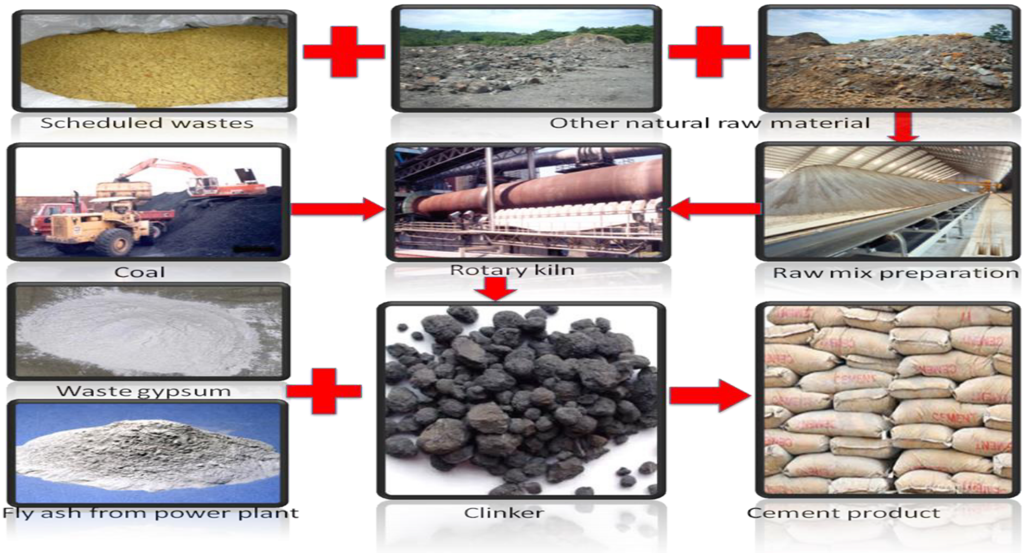
Principle	Description
The waste management hierarchy should be respected	– Waste should be co-processed in cement kilns where more ecologically and economically robust methods of recovery are not available – Co-processing should be considered an integrated part of waste management – Co-processing should be in line with the Basel and Stockholm Conventions and other relevant international environmental agreements
Additional emissions and negative impacts on human health must be avoided	– Negative effects of pollution on the environment and human health must be prevented or kept at a minimum – Air emissions from cement kilns co-processing waste cannot be statistically higher than those not involved in co-processing waste
The quality of the cement must remain unchanged	– The product (clinker, cement, concrete) must not be used as a sink for heavy metals – The product must not have any negative impacts on the environment (for example, as determined by leaching tests) – The quality of the product must allow for end-of-life recovery
Companies that co-process must be qualified	– Assure compliance with all laws and regulations – Have good environmental and safety compliance records – Have personnel, processes, and systems in place committed to protecting the environment, health, and safety – Be capable of controlling inputs to the production process – Maintain good relations with public and other parties involved in local, national and international waste management schemes

Table 2 - the general principles for co-processing of hazardous and other wastes in cement kilns
Source: GTZ (2006)

6.1.5 Figure 3 illustrates the use of scheduled wastes as alternative raw material, alternative fuel and cement additive in cement plant.

Figure 3 – Use of scheduled wastes in cement plant





6.2 Selection Of Wastes For Co-Processing

6.2.1 Co-processing should include a thorough selection of waste to avoid and/or reduce emissions and risk of damage to the environment or public health as well as to maintain the quality of cement products.

6.2.2 The use of scheduled wastes in cement manufacturing should add value to the process, for example the heating value and the material value of the mineral composition, while in compliance to the relevant regulations and permit requirements as well as the plant's ability to handle any particular waste stream. The use of cement kilns as a disposal operation not leading to resource recovery (i.e., the destruction or irreversible transformation of scheduled wastes constituents), should be considered only if there are environmental benefits : for example, NOx reduction through flame cooling or when there is no other cost-effective and environmentally sound disposal option at the local level.

6.2.3 Blending and mixing of different scheduled wastes streams may be required to ensure a homogeneous feedstock of alternative raw material that meets specifications for use in a cement kiln. Blending of scheduled wastes should not, however, be conducted with the aim of lowering the concentration of hazardous constituents to circumvent regulatory requirements. As a general principle, the mixing of wastes should be prevented from leading to the application of an unsuitable (non-environmentally sound) disposal operation (EIPPCB, 2006) .

6.3 Scheduled Wastes Suitable For Co-Processing In Cement Kilns

6.3.1 The selection of suitable scheduled wastes to be used as alternative raw material in co-processing is influenced by various factors includes:

(a) the nature of the waste;

(b) its hazardous characteristics;

(c) available waste management operations;

(d) kiln operation; raw material and fuel compositions; waste feed points;

(e) exhaust gas cleaning process;

(f) resulting clinker quality;

(g) general environmental impacts;

(h) probability of formation and release of POPs;

(i) particular waste management considerations; and

(j) regulatory compliance; and public and government acceptance (Van Oss and Padovani, 2003; GTZ, 2006; UNEP, 2007; EIPPCB, 2010).

6.3.2 The operator should develop a waste evaluation procedure to assess potential impacts on the health and safety of workers and the public, plant emissions, operations and product quality, by taking the recommended variables as in **Table 3**, into consideration when selecting the waste (WBCSD, 2005; UNEP, 2007):

Variables		Explanation
Kiln operation	Alkali (sodium, potassium, etc.), sulphur and chloride content	• Excessive inputs of these compounds may lead to build-up and blockages in the kiln system. Where these cannot be captured in the cement clinker or kiln dust, a bypass may be required to remove excess compounds from preheater/precalciner kiln systems. High alkali content may also limit recycling of CKD in the kiln itself
	Heating (calorific) value	• The key parameter for the energy provided to the process
	Water content	• Overall moisture content may affect productivity, efficiency and also increase energy consumption. The water content of waste needs to be considered in conjunction with that of conventional fuels and/or raw feed materials
	Ash content	• The ash content affects the chemical composition of the cement and may require an adjustment of the composition of the raw mix
	Exhaust gas flow rate and waste feed rate	• Sufficient residence time is needed for the destruction of organics and to prevent incomplete combustion due to waste overcharging

	Others	• Stability of operation (for example, duration and frequency of CO trips) and the waste's state (liquid, solid), preparation (shredded, milled) and homogeneity
Emissions	Organic content	• Organic constituents are associated with emissions of CO_2 and may result in emissions of CO and other products of incomplete combustion (PICs) if waste is fed through unsuitable points or during unstable operating conditions
	Chloride content	• Chlorides may combine with alkalis to form fine, difficult to control particulate matter. In some cases, chlorides have combined with ammonia present in the limestone feed. This produces highly visible detached plumes of fine particulate with a high ammonium chloride content
	Metals content	• The non-volatile behaviour of most heavy metals allows most to pass straight through the kiln system and be incorporated into the clinker. • Introduced volatile metals will partly be recycled internally by evaporation and condensation until equilibrium is reached, the other part being emitted in the exhaust gas. • Thallium, mercury and their compounds are highly volatile as to a lesser extent are cadmium, lead, selenium and their compounds. • The fact that dust control devices can only capture the particle-bound fraction of heavy metals and their compounds needs to be taken into account.

		• Wood treated with preservatives containing copper, chromium and arsenic also requires special consideration with regard to the efficiency of the exhaust gas cleaning system. • Mercury is a highly volatile metal, which, depending on the exhaust gas temperature is present in both particle-borne and vapour forms in the air pollution control equipment (EIPPCB, 2010).
	Alkali bypass exhaust gas	• Alkali bypass exhaust gas can be released from either a separate exhaust stack or from the main kiln stack in systems equipped with an appropriate bypass. • According to the United States Environmental Protection Agency (1998) the same hazardous air pollutants are found in both the main and alkali bypass stacks. Where an alkali bypass system is installed, appropriate control of the exhaust to atmosphere also needs to be provided on the bypass exhaust, similar to that mandated for the main exhaust stack (UNEP, 2007)
	Sulphur content	• High sulphur content in raw materials, fuel and waste may result in the release of SO_2
Clinker, cement and final product quality	Phosphate content	• High levels of phosphate may delay setting time
	Flourine content	• High levels of fluorine will affect setting time and strength development
	Chlorine, sulphur and alkali content	• High levels chlorine, sulphur and alkali may affect overall

		product quality
	Thallium and chromium content	• Thallium and chromium content can adversely affect cement quality and may cause allergic reactions in sensitive users. • Leaching of chromium from concrete debris may be more prevalent than leaching of other metals (Van der Sloot et al., 2008). Leaching test is required to be carried out if the cement plant intends to use raw materials or scheduled wastes containing chromium. • Limestone, sand and clay contain chromium, making its content in cement both unavoidable and highly variable. The Norwegian National Institute of Occupational Health (Kjuus et al., 2003) reviewed several studies of chromate allergy, especially those involving construction workers. It found that the main sources of chromium in cement came from raw materials, refractory bricks in the kiln and chromium steel grinders. The relative contribution of these factors may vary depending on the chromium content of the raw materials and the manufacturing conditions. Minor sources include both conventional and alternative fuels (EIPPCB, 2010). • Cement eczema can be caused by exposure to wet cement with a high pH, which induces irritant contact dermatitis and by an immunological reaction to chromium that elicits allergic contact dermatitis (Kjuus et al., 2003). • Where there is a possibility of contact with the skin, cement

		and cement-containing preparations may not be used or placed on the market in the European Union, if they contain, when hydrated, more than 0.0002 per cent soluble chromium (VI) of the total dry weight of the cement. • As the main chromate source is from the raw material, a reduction in chromium levels (VI) in cement requires that a reducing agent is added to the finished product. The main reducing agents used in Europe are ferrous sulphate and tin sulphate (EIPPCB, 2010)
	Leachable trace elements:	• Heavy metals are present in all feed materials, conventional and otherwise. However under certain test conditions, leached concentrations from concrete of other metals besides chromium may approach drinking water standards (GTZ, 2006).

Table 3: Variables that should be taken in consideration when selecting Scheduled Wastes for co-processing

6.3.3 Only waste of known composition, energy and mineral value is suitable for co-processing in cement kilns. To verify the suitability of a particular scheduled wastes stream to be used in co-processing at their cement plant, the operators should develop a specific Waste Acceptance Criteria for each of the following purposes:

(a) Scheduled wastes used as alternative raw material;

(b) Scheduled wastes used as alternative fuel; and

(c) Scheduled wastes used as cement additive.

6.3.4. Cement plant shall establish the Waste Acceptance Criteria based on their plant's capability and the criteria should at least include the following parameters and limits:

WASTE ACCEPTANCE CRITERIA FOR ALTERNATIVE RAW MATERIAL:

Note: Analysis Should Be In Dry Basis:

No.	Parameter	Minimum	
1	SiO_2 (%)	Total of 2 major oxides should be >30% in dry basis	
2	Fe_2O_2 (%)		
3	Al_2O_3 (%)		
4	CaO (%)		
5	Cl (ppm)	Maximum 2%. Waste with total halogenated organic with > 1% must be only used at the main burner	
6	Moisture content (%)	≤70 % in waste (subject to the characteristic of the waste)	
7	Pb (mg/kg)	Total heavy metals: ≤100,000 ppm in ARM	
8	Cr (mg/kg)		
9	As (mg/kg)		
10	Sn (mg/kg)		
11	Se (mg/kg)		
12	Ni (mg/kg)		
13	Te (mg/kg)		
14	Co (mg/kg)		
15	V (mg/kg)		
16	Sb (mg/kg)		
17	Mn (mg/kg)		
18	Zn (mg/kg)	<30,000 in total input: ARM	
19	Cu (mg/kg)	<30,000 in total input: ARM	
20	Hg (mg/kg)	<10	Total volatile metal: ≤100 ppm
21	Tl (mg/kg)	-	
22	Cd (mg/kg)	-	
23	Total organic content	<1% if ARM fed in cold part of the process	

Table 4: Minimum Waste Acceptance Criteria for scheduled waste used as alternative raw material

WASTE ACCEPTANCE CRITERIA FOR ALTERNATIVE FUEL:

Note: Analysis Should Be In Ash Basis:

<table>
<tr><th>No.</th><th>Parameter</th><th colspan="2">Minimum</th></tr>
<tr><td>1</td><td>Cl (ppm)</td><td colspan="2">Maximum 2%. Waste with total halogenated organic with > 1% must be only used at the main burner</td></tr>
<tr><td>2</td><td>Moisture content (%)</td><td colspan="2">≤70 % in waste (subject to the characteristic of the waste)</td></tr>
<tr><td>3</td><td>Pb (mg/kg)</td><td colspan="2" rowspan="11">Total heavy metals:
≤10,000 ppm in AF</td></tr>
<tr><td>4</td><td>Cr (mg/kg)</td></tr>
<tr><td>5</td><td>As (mg/kg)</td></tr>
<tr><td>6</td><td>Sn (mg/kg)</td></tr>
<tr><td>7</td><td>Se (mg/kg)</td></tr>
<tr><td>8</td><td>Ni (mg/kg)</td></tr>
<tr><td>9</td><td>Te (mg/kg)</td></tr>
<tr><td>10</td><td>Co (mg/kg)</td></tr>
<tr><td>11</td><td>V (mg/kg)</td></tr>
<tr><td>12</td><td>Sb (mg/kg)</td></tr>
<tr><td>13</td><td>Mn (mg/kg)</td></tr>
<tr><td>14</td><td>Zn (mg/kg)</td><td colspan="2"><30,000 in total input: AF</td></tr>
<tr><td>15</td><td>Cu (mg/kg)</td><td colspan="2"><30,000 in total input: AF</td></tr>
<tr><td>16</td><td>Hg (mg/kg)</td><td><10</td><td rowspan="3">Total volatile metal:
≤100 ppm</td></tr>
<tr><td>17</td><td>Tl (mg/kg)</td><td>-</td></tr>
<tr><td>18</td><td>Cd (mg/kg)</td><td>-</td></tr>
<tr><td>19</td><td>Calorific heating value</td><td colspan="2">> 500 kcal/kg (as dried basis)</td></tr>
</table>

Table 5: Minimum Waste Acceptance Criteria for scheduled waste used as alternative fuel

Waste Acceptance Criteria for cement additive

1. Low content of organic carbon

2. Does not contain radioactive component (example: Radon, ect.)

The cement plant shall ensure that the scheduled wastes received to be co-processed fulfilled the requirements specified in the Waste Acceptance Criteria before it is been sent to the cement plant to be co-processed.

6.3.5 The following scheduled wastes are not allowed for co-processing in cement kilns:

(a) Radioactive or nuclear waste;

Cement plants are not designed or operated to meet safety and health requirements for radioactive waste management. The preferred disposal approach is concentration (reduction of volume) and containment of radionuclides through a conditioning process to prevent or substantially reduce dispersion in the environment.

(b) Electric and electronic waste;

Electric and electronic waste contains valuable resources, such as precious metals and recycling should be the preferred option. Co-processing of plastic components might be an option but only after appropriate disassembly and sorting.

(c) Whole batteries;

Co-processing of batteries would lead to concentrations of pollutants in the cement and air emissions. Batteries contain valuable resources such as lead and recycling should be the preferred waste management option.

(d) Corrosive waste, including mineral acids;

Corrosive wastes may cause corrosion and fouling problems in equipment not specifically designed for this type of waste. This being usually the case with pre-processing, storage and injection systems. Wastes with high chlorine and sulphur contents such as some mineral acids may also have a negative effect on clinker production or product quality. High sulphur contents may also result in the release of sulphur oxides (UNEP, 2007).

(e) Explosives;

Explosive waste should not be co-processed in the cement kiln given the adverse effects on process stability. There are also occupational safety concerns due to the risk of uncontrolled explosions during transport and pre-processing activities.

(f) Cyanide bearing waste;

(g) Asbestos-containing waste;

(h) Infectious medical waste;

(i) Chemical or biological weapons destined to destruction;

(j) Waste consisting of, containing or contaminated with mercury above permitted limits;

The high volatility of mercury poses a problem regarding air emissions. Inputs of wastes consisting of, containing or contaminated with mercury to the kiln should be controlled and kept to a minimum

(k) Waste of unknown or unpredictable composition, including unsorted municipal waste.

In general these wastes are not recommended because of health and safety concerns, potentially negative impacts on kiln operation, clinker quality and air emissions, and when a preferable alternative waste management option is available

6.3.6 Scheduled wastes that are, in principle, well-suited for co-processing in cement kilns include: tank bottom sludges, acid alkyl sludges, oil spills and acid tars from petroleum refining, natural gas purification and pyrolytic treatment of coal; waste machining oils; waste hydraulic oils and brake fluids; bilge oils; oil/water separator sludges, solids or emulsions; washing liquids and mother liquors,still bottoms and reaction residues from the manufacture, formulation, supply and use of basic organic chemicals, plastics, synthetic rubber, man-made fibres, organic dyes, pigments, organic pesticides andpharmaceuticals; waste ink; wastes from the photographic industry; tars and other carbon-containing wastes from anode manufacture (aluminium thermal metallurgy); wastes from metal degreasing and machinery maintenance; wastes from textile cleaning and degreasing of natural products; process wastes from the electronic industry (GTZ/Holcim, 2006).

6.3.7 Waste streams with recoverable energy value meet specifications can be used as fuels in a cement kiln to replace a portion of conventional fuels and waste streams containing useful components such as calcium, silica, alumina and iron can be used to replace raw materials such as clay, shale and limestone. Wastes meeting both sets of requirements may be suitable for processing for both energy and materials recovery.

6.3.8 **Figure 4** outlined the decision to distinguish between operations that lead to resource recovery and disposal.

6.4 Trial Burns Of Scheduled Wastes For Co-Processing In Cement Kilns

6.4.1 A trial burn is used to determine the facility's destruction and removal efficiency (DRE) or destruction efficiency (DE), to verify its ability to efficiently destroy POPs in an irreversible and environmentally sound manner. This involves the selection, sampling and analysis of a principal organic hazardous constituent (POHC) in the waste feed to determine its input and emission rates. A trial burn typically consists of a series of tests, one for each set of operating conditions in the facility. Three runs are normally performed for each test.

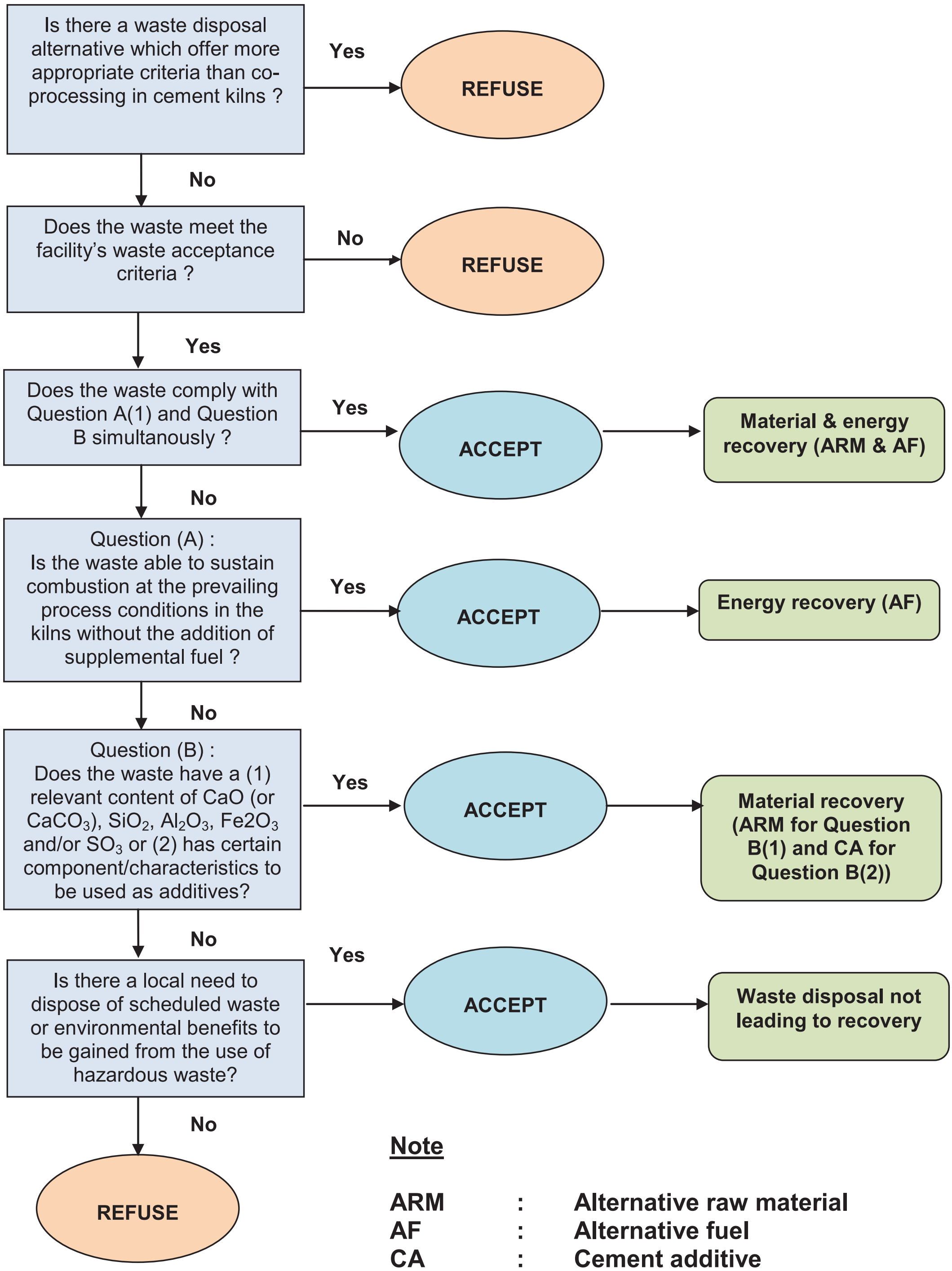
6.4.2 During the trial burn, the operator should establish the operating limits for maximum scheduled wastes feed and maximum kiln production rate. The operator shall also schedule a sampling and analysis of emission by competent and accredited party.

6.4.3 The trial burn should be carried out by existing or new cement plant intends to implement co-processing of scheduled wastes for the first time.

6.5 OTHERS

6.5.1 Other important aspects that should be taken into considerations when the operators of cement plant implement co-processing activity are the requirement for (i) a comprehensive programme on quality assurance (QA) and quality control (QC); (ii) health and safety program; and (iii) the involvement of stakeholders as well as public communication. Further information on three (3) aspects as outlined by UNEP are detailed out in **Annex 2**, **Annex 3** and **Annex 4**.

Figure 4: Decision to distinguish between operations that lead to resource recovery and/or disposal



Note

ARM	**:**	**Alternative raw material**
AF	**:**	**Alternative fuel**
CA	**:**	**Cement additive**

7.0 ENVIRONMENTALLY SOUND CO-PROCESSING OF SCHEDULED WASTES IN CEMENT KILNS

7.1 Waste Acceptance And Pre-Processing

7.1.1 Before a cement plant decide to receive scheduled wastes to be used as alternative raw material, the operator should investigate the nature and composition associated with the waste, and all relevant information should be passed by the waste generator to the operator. The waste should also be sampled and sent to accredited laboratories for chemical analysis.

7.1.2 Operators of cement plant should ensure that the scheduled wastes received is in compliance to the Waste Acceptance Criteria of alternative raw material or alternative fuel that has been established beforehand.

7.1.3 The scheduled wastes usually will require a pre-processing to produce a homogeneous waste stream before it is co-processed in the cement kilns.

7.1.4 The operators shall develop a “Standard Operating Procedure” on Waste Acceptance and Pre-Processing that detailed out the management of scheduled wastes received to ensure it is manage properly and such activity will not give any adverse effect to the process, environment as well as human health. A general recommendation as outlined by UNEP as in **Annex 5**.

7.2 Co-Processing

7.2.1 For optimal performance (co-processing without additional emissions) alternative fuels and raw materials should be fed to the cement kiln through appropriate feed points, in adequate proportions and with proper waste quality and emission control systems.

7.2.2 Co-processing has the following characteristics during the production process (GTZ/Holcim, 2006):

(a) The alkaline conditions and the intensive mixing favour the absorption of volatile components from the gas phase. This internal gas cleaning results in low emissions of components such as SO2, HCl, and most of the heavy metals, with the exception of mercury, cadmium and thallium;

(b) The clinker reactions at 1450°C allow the chemical binding of metals and the incorporation of ashes to the clinker;

(c) The direct substitution of primary fuel by high calorific waste material causes a higher efficiency on energy recovery in comparison to other ‘waste to energy’ technologies.

7.2.3 A general recommendation as outlined by UNEP as in **Annex 6**.

8.0 QUALITY OF CEMENT PRODUCT

8.1 The cement product should comply with MS EN 197-1.

9.0 GOVERNMENT POLICY AND LEGAL REQUIREMENT

9.1 General Requirements

9.1.1 Below are the general requirements specific to cement kilns co-processing hazardous wastes on a routine basis as outlined by Karstensen (2008a, 2009a):

(a) Compliance with all required national/local licenses, permits, authorisations and emissions and relevant national and local regulations as outlined under Environmental Quality Act 1974 and all related Regulations, Orders and Rules under the Act.

(b) Suitable location, technical infrastructure, storage and processing equipment

(c) Reliable and adequate power and water supply

(d) Application of BAT for air emissions pollution prevention and control, along with continuous emission monitoring to ensure compliance with regulation and permits (verified through regular baseline monitoring)

(e) Exit gas conditioning/cooling and low temperatures (< 200°C) in the air pollution control device to prevent dioxin formation

(f) Clear management and organisational structure with unambiguous responsibilities, reporting lines and feedback mechanism

(g) Qualified and skilled employees to manage wastes and health, safety and environmental issues

(h) Adequate emergency and safety equipment and procedures, and regular training

(i) Authorised and licensed collection, transport and handling of hazardous wastes

(j) Safe and sound receiving, storage and feeding of hazardous wastes

(k) Access to an adequate laboratory facilities and equipment for hazardous waste acceptance and feeding control

(l) Adequate record keeping of wastes and emissions

(m) Adequate product quality control routines

(n) Implementation of an environmental management system (EMS) including a continuous improvement programme and ISO 14000 certification

(o) Independent audits (government sanctioned or otherwise), emission monitoring and reporting

(p) Stakeholder dialogues with local community and authorities, and mechanisms for responding to comments and complaints

(q) Open disclosure of performance and compliance verification reports on a regular basis

9.2 Requirements Under Environmental Quality Acts 1974 For Cement Factory Implementing Co-Processing

9.2.1 All cement plant implementing co-processing of scheduled wastes as alternative raw material, alternative fuel or cement additive shall be licenced by the Department of Enviroment as off-site treatment facilities as specified in Order 3(b), Environmental Quality (Prescribed Premises) (Scheduled Wastes Treatment and Disposal Faciities, 1989.

9.3 Emission Limits

9.3.1 Emission limits for cement plant implementing co-processing of scheduled wastes are as below:

NO.	PARAMETER		LIMIT
1	Dust	-	**50 mg/Nm^3**
2	Sulphur dioxide	SO_2	**400 mg/ Nm^3**
3	Nitrogen Oxides	NO_2	**800 mg/ Nm^3**
4	Hydrogen Chloride	HCl	**10 mg/ Nm^3**
5	Volatile Organic Compound	TOC	**20 mg/ Nm^3**
6	Chlorine	Cl_2	**200 mg/ Nm^3**
7	Mercury	Hg	**0.05 mg/ Nm^3**
8	Cadmium	Cd	**$<$0.05 mg/ Nm^3**
9	Thallium	Tl	
10	Arsenic	As	**Total 2.5 mg/ Nm^3**
11	Cobalt	Co	
12	Lead	Pb	

13	Copper	Cu	
14	Antimony	Sb	
15	Chromium	Cr	
16	Nickel	Ni	
17	Vanadium	V	
18	Manganese	Mn	
19	Zinc	Zn	**100 mg/ Nm^3**
20	Hydrogen Floride	HF	**1 mg/ Nm^3**
21	Dioxin & Furan	D&F	**0.1ng/ Nm^3**
22	Smoke (Ringelmann chart)	-	**No 1**
23	Ammonia & ammonia compound	NH3	**30 mg/ Nm^3**
24	Benzene	-	**5 mg/ Nm^3**

Table 6: Emissions limit for cement plant implementing co-processing of scheduled wastes

9.3.2 The emission limits in Table 6 applicable to the following cement plant:

(a) New or existing cement plant implementing co-processing for the first time;

(b) For existing cement plant which has been licenced to co-process scheduled wastes shall comply to the emission limits as stipulated in the conditions of the licence. However, the cement plant shall upgrade their air pollution control system and make necessary improvement to comply to the new emission limit after year 2019.

9.4 Application procedure

9.4.1 In order to implement co-processing of scheduled wastes, the cement plant shall initially obtain the following approvals from Department of Environment State Office:

(a) For existing cement plant has been in operation before 1987, a new EIA report shall be submitted to the DOE for co-processing activity subject to the prescribed activity under activity 18(a)(ii) of the Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) 1987;

(b) For the expansion of existing cement plant involves an increase in capacity of more than 50% and the process of co-processing, a new Detailed EIA report shall be submitted to the DOE for consideration;

(c) Written approval under Section 19 of the Environmental Quality Act 1974; and

(d) Licence as off-site treatment facility under Section 18 of the Environmental Quality Act 1974.

9.4.2 As a licenced premis of an off-site treatment facility, any proposal to receive new code or new source of scheduled wastes to be co-processed, the cement plant shall require a few step approval from the Department of Environment (DOE) as below:

(a) Co-processing activities are believed to have effects residue. Therefore, all cement plant shall submit additional information(addendum) to DOE together with other information required during the process of In Principle Approval for the usage, increasing the quantity and types of wastes being allowed;

(b) The addendum should detail the types of scheduled wastes that will be used and reviewing the effectiveness of pollution control system to ensure the use of scheduled wastes do not effect on the environment especially the sensitive receptor;

(c) The Addendum is required as a basis for considering the use of scheduled wastes as well as to allow amendments to the conditions of approval of the EIA made by referring to the relevant provisions of information on raw materials including cumulative raw materials

(d) In Principle Approval from Department of Environment Headquarters. Assessment will be carried out to study the suitability of the scheduled wastes to be used as alternative raw material, alternative fuel or cement additive;

(b) Operational approval from Department of Environment State Office. This will also require amendment to the licence condition to include new code or new source scheduled wastes for existing code in the licence.

ANNEX 1
Clinker Production Process

ANNEX 1 - CLINKER PRODUCTION PROCESS

A. Introduction

1. Cement production involves the heating, calcining and sintering of a carefully proportioned mixture of calcareous and argillaceous materials, usually limestone and clay, to produce cement clinker, which is then cooled and ground with additives such as gypsum (a setting retardant) to make cement. This process typically requires approximately 2.9 to 6.7 GJ of energy depending on the kiln technology employed (IEA, 2007) and 1.5 to 1.7 tonnes of raw materials per tonne of clinker produced (Szabó et al, 2003); the portion of raw material that does not become clinker is either lost on ignition or becomes CKD (U.S. EPA, 1993). 'Wet' processes also use water to make the raw slurry that feeds the kilns; about 600 kg of water is used in the manufacture of one tonne of cement, some of which is returned to the environment (EA, 2005).

2. Manufacturers use clinker and specific constituents in various proportions to produce cements that meet different physical and chemical requirements for specific applications. By far the most common hydraulic cements in use today are either Portland cements or 'blended' cements (van Oss and Padovani, 2003). The standard specifications with which Portland cements must comply are similar (albeit not identical) in all countries and various names are used to define the material. Blended cements, also called composite cements, are mixtures of Portland cement with one or more pozzolanic additives or extenders (sometimes collectively termed 'supplementary cementitious materials'), such as pozzolana (volcanic ashes), certain types of fly ash (from coal-fired powerplants), granulated blast furnace slag, silica fume, or limestone. These materials commonly make up about 5 to 30 per cent by weight of the total blend, but can be higher (van Oss, 2005). The designations for blended cements differ worldwide.

3. Although a variety of cement types are produced worldwide, cement production follows essentially the same process, as described below.

B. Conventional raw materials and fuel

4. The raw materials for cement must yield the oxides required for clinker in the approximate proportions noted in **Table 1A**, with the major requirement being calcium oxide (CaO). In practical terms this means that naturally occurring calcareous deposits, such as limestone, marl or chalk, which consist essentially of calcium carbonate ($CaCO_3$), are required. Clay or shale typically provides the remaining components. To correct for minor deficiencies in one or more oxides in the primary raw materials, 'corrective' constituents[1] such as iron ore, bauxite or sand, may be added to adapt the chemical composition of the raw mix to the requirements of the process and product specifications (Taylor, 1997; Karstensen, 2007b). Generally, most, but not all, of the raw materials are mined adjacent to or within a few miles of the cement plant.

1 Sometimes called "accessory" or 'sweetener' materials (van Oss, 2005).

TABLE 1A - CHEMICAL COMPOSITION OF ORDINARY PORTLAND CEMENT CLINKER AND CONVENTIONAL RAW MATERIALS

Constituent	Clinker	Limestone, lime marl, chalk	Clay	Sand	Iron ore	Bauxite
SiO_2	19.71-24.25%	0.5-50%	33-78%	80-99%	4-11%	2.9%
Al_2O_3	3.76-6.78%	0.1-20%	7-30%	0.5-7%		
TiO_2	0.21-0.52%	0.0-0.7%	0.2-1.8%	0.0-0.5%		
$Al_2O_3 + TiO_2$			7-30%	0.5-2%	0.2-3%	57.5%
Fe_2O_3	1.29-4.64%	0.2-5.9%	4.0-15%	0.0-4%		
Mn_2O_3	0.03-0.68%	0.02-0.15%	0.09%	0.051%		
$Fe_2O_3 + Mn_2O_3$		0.1-10%	2-15%	0.5-2%	19-95%	22.8%
CaO	63.76-70.14%	20-55%	0.2-25%	0.1-3%	0.1-34%	2.4%
MgO	0.00-4.51%	0.2-6%	0.3-5%	0.3-0.5%	≤1.5%	0.04%
K_2O	0.31-1.76%	0-3.5%	0.4-5%	0.2-3%	Traces	0.04%
Na_2O	0.03-0.335	0.0-1.5%	0.1-1.5%	0.0-1%	Traces	0.02%
Cl		0.0-0.6%	0.0-1%	Traces		
P_2O_5	0.02-0.27%	0.0-0.8%	0.0-1.0%	0.0-0.1%		
Loss on ignition ($CO_2 + H_2O$)	0.09-1.56%	2-44%	1-20%	≤5	0.1-30%	13.5%

Sources: EIPPCB (2010) and CEMBUREAU (1999)

5. Natural forms of $CaCO_3$ consist of coarser or finer crystals of calcite. Limestone is microcrystalline $CaCO_3$ with clay as the main impurity. Chalk is a very fine grained, porous marine limestone composed almost entirely of microscopic fossils. The main constituents of shale and clay are clay minerals, finely divided quartz and, sometimes, iron oxides. Traditionally, wet materials (chalk and clay) have been used in 'wet' or 'semi-wet' kiln processes, and dry materials (limestone) have been used in the 'dry' or 'semi-dry' processes (EA, 2005).

6. Around 80-90 % of raw material for the kiln feed is limestone; clayey raw material accounts for between 10-15 %, although the precise amounts will vary (BGS, 2005). In addition to the chemical composition of the desired product, the proportion of each type of raw material used in a given cement kiln will depend on the composition of the specific materials available to the operator, which is tested on a regular basis.

7. The proportioning process takes into account the ratios of calcium, silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) needed to produce good quality clinker, as well as the 'burnability' of the raw mix (i.e., the requirements in terms of time, temperature, and fuel to process the material) (U.S. EPA, 1993). In addition, kiln operators pay close attention to the presence of 'impurities' in the mixture, including magnesia, sulphur, chlorides, and oxides of potassium and sodium (referred to as 'alkalies'). Magnesia (MgO) can be desirable to some extent because it acts as a flux at sintering temperatures, facilitating the burning process, however MgO levels are carefully monitored because they can lead to the production of clinker that is unsound if not cooled rapidly[2]. Alkalies can react in the cool end of the kiln with sulphur dioxide, chlorides, and carbon dioxide contained in the kiln gas and can lead to operational problems (U.S. EPA, 1993).

8. The raw materials used in the cement production process naturally contain metals and halogens. Thus, antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver, thallium, vanadium, zinc, bromine, chlorine, fluorine, and iodine are typically present in the raw materials. The amounts of these components depend on the geological formations from which the raw materials are mined. In addition to the metals and halogens present, the raw materials can contain organic compounds (Mantus, 1992). Average values and range of concentrations of these constituents are presented in **Table 1B**.

9. Cement production also has high energy requirements, which typically account for 30-40 % of the production costs (excluding capital costs). Most cement kilns today use coal and petroleum coke as primary fuels, and to a lesser extent, natural gas and fuel oil. As well as providing energy, some of these fuels, especially coal or lignite, produce significant quantities of ash similar in composition to the argillaceous component.

10. Many plants routinely burn more than one fuel. For example, when firing up a cold kiln, natural gas or fuel oil is commonly used for the slow, warm-up phase necessary to prevent thermal overstressing of the kiln's refractory brick lining. Once the kiln is sufficiently hot, it will be switched over to coal and/or coke (generally petroleum coke) for production operations. (van Oss, 2005)

11. Coal can contain significant quantities of sulphur, trace metals, and halogens, and their concentrations are dependent on the area in which the coal was mined. The typical concentration of trace elements in the primary fuels is as in **Table 1C**. Sulphur (in the form of SO_3) will vaporize in the kiln to form sulphur dioxide (SO_2),

2 Such clinker used to make concrete can cause destructive expansion of hardened concrete through slow reaction with water.

and condense in the form of sulphates. Within the kiln, these sulphates combine with calcium and potassium, causing operational problems in the cool end of the kiln. Halogens are of concern because chlorides can cause operational problems similar to those caused by sulphur. Chlorine concentrations in coal can range from 100 to 2800 parts per million. (U.S. EPA, 1993)

12. Both heat and electricity consumption vary significantly with kiln technology as presented in **Table 1D** and, for the same general technology, plants operating multiple kilns tend to have higher energy requirement per tonne of overall output capacity than the plants with the same overall capacity that operate a single kiln. Wet kilns consume more fuel on a unit basis than the dry kilns because of the need to evaporate the water in the slurry feed and the much larger size of the wet kilns. (van Oss, 2005).

TABLE 1B - TRACE ELEMENT CONCENTRATIONS (IN PARTS PER MILLION) IN CONVENTIONAL RAW MATERIALS (Min = minimum value; Max = maximum value; AV = average value; n.a. = no data available)

Constituent	Limestone Min-Max (AV)	Marl Min-Max (AV)	Clay Min-Max (AV)	Sand Min-Max (AV)	Iron ore Min-Max (AV)	Gypsum/anhydrite Min-Max (AV)
As	0.1-15 (3)	0.2-12 (6)	2-100 (14)	0.4-42 (11)	2-1200 (37)	0.2-3.5 (1.5)
Be	0.01-12 (0.3)	n.a.-1 (0.5)	1-7 (3)	0.6-1.5 (1.0)	0.8-2 (1)	0.02-0.9 (0.2)
Cd	0.02-2 (0.2)	0.02-0.5 (0.3)	0.01-1 (0.2)	0.01-1 (0.2)	0.02-15 (6)	0.03-2.3 (0.15)
Co	0.1-7 (3)	n.a.-28 (5)	6-25 (20)	0.3-37 (11)	109-183 (144)	0.02-3.9 (1)
Cr	0.5-184 (14)	1.2-71 (28)	15-260 (85)	1-220 (19)	8-1400 (495)	1-27.3 (8.8)
Cu	5-57 (11)	4.9-35 (12)	10-285 (43)	1.2-85 (10)	(1520)	0.3-12.8 (7)
Hg	0.005-0.1 (0.04)	0.005-0.1 (0.03)	0.01-0.5 (0.2)	0.01-1 (0.02)	n.a.-1 (0.5)	0.00625-1.3 (0.1)
Mn	250-3300 (500)	n.a.-3300 (360)	n.a.-2500 (600)	46-2040 (194)	900-1200 (1090)	n.a.
Ni	1.4-131 (18)	1.5-57 (16)	7-236 (63)	1-73 (13)	5-815 (331)	0.3-14.5 (5.5)

Pb	0.27-151 (18)	0.3-57 (12)	1-219(25)	0.7-70 (10)	4-8700 (350)	0.2-20.5 (7)
Sb	0.2-27 (1)	n.a.-27 (4)	0.5-13 (2)	0.3-12 (7)	(26)	0.1-5 (1)
Se	0.4-30 (0.6)	n.a. (1)	n.a.-2.5 (0.5)	n.a. (1)	(8)	0.6-17 (0.8)
Sn	0.9-24 (4)	n.a.-24 (3)	1.6-30 (5)	1.8-40 (3)	n.a.-500 (25)	n.a.
Te	n.a. (0.7)	n.a. (1)	n.a. (0.5)	n.a. (0.5)	n.a.-13 (10)	n.a.
Tl	0.05-3 (0.3)	0.05-0.68 (0.6)	0.1-1.6 (0.5)	0.05-1 (0.2)	0.1-400 (2)	0.1-1.0 (0.3)
V	5-80 (26)	n.a.-49 (20)	30-300 (130)	2-240 (50)	10-690 (256)	1-27.8 (13.5)
Zn	0.1-229 (30)	22-79 (48)	2-304 (78)	4.2-112 (25)	24-9400 (3288)	1-59 (19)
Br a/	n.a. (5.9)	n.a.	1-58	n.a.	n.a.	n.a.
Cl a/	50-240	n.a.	15-450	n.a.	n.a.	n.a.
F a/	100-940	n.a.	300-990	n.a.	n.a.	n.a.
I a/	0.25-0.75	n.a.	0.2-2.2	n.a.	n.a.	n.a.

a/ Mantus (1992)
Source: Achternbosch et al. (2003), unless otherwise noted.

TABLE 1C - TRACE ELEMENT CONCENTRATIONS (IN PARTS PER MILLION) IN PRIMARY FUELS
(Min = minimum value; Max = maximum value; n.a. = no data available)

Constituent	Anthracite Min-Max	Bituminous coal Min-Max	Lignite Min-Max	Petroleum coke Min-Max
As	1-200	n.a.	0.1-12	0.2-0.8
Be	0-8	n.a.	0.04-0.6	0.02-0.03
Cd	0.01-10	n.a.	0.06-2.4	0.04-4
Co	0.5-43	n.a.	0.5-4.2	n.a.
Cr	1-260	n.a.	0.9-20	0.9-104
Cu	0.30-60	n.a.	0.4-15	n.a.
Hg	0.01-3	n.a.	0.01-0.7	0.01-0.09
Mn	5-356	n.a.	50-160	n.a.
Ni	1-110	n.a.	0.6-29	24-355
Pb	5-270	n.a.	0.7-34	1-102
Sb	0.05-5	n.a.	0.04-2.5	n.a.
Se	0-6	n.a.	0.4-25	n.a.
Sn	1.3-7.8	n.a.	0.5-15	n.a.
Te	0.2-5.0	n.a.	0.1-10	n.a.
Tl	0.1-5	n.a.	0.05-0.4	0.04-3.1
V	10-250	n.a.	0.1-84	45-1435
Zn	4.5-405	n.a.	1-70	16-220
Br a/	n.a.	7-11	n.a.	n.a.
Cl a/	n.a.	100-2800	n.a.	n.a.
F a/	n.a.	50-370	n.a.	n.a.
I a/	n.a.	0.8-11.2	n.a.	n.a.

a/ Mantus (1992)

Source: Achternbosch et al. (2003), unless otherwise noted.

TABLE 1D - ENERGY REQUIREMENTS FOR CLINKER MANUFACTURE

Process	Fuel consumption, GJ/tonne
Vertical shaft kiln	3.7-6.6
Wet process	5.9-6.7
Long dry process	4.6
1 stage cyclone preheater	4.2
2 stage cyclone preheater	3.8
4 stage cyclone preheater	3.3
4 stage preheater + precalciner	3.1
5 stage preheater + precalciner	3.0-3.1
6 stage preheater + precalciner	2.9

Source: IEA (2007) and Szabó (2003)

C. Manufacturing process

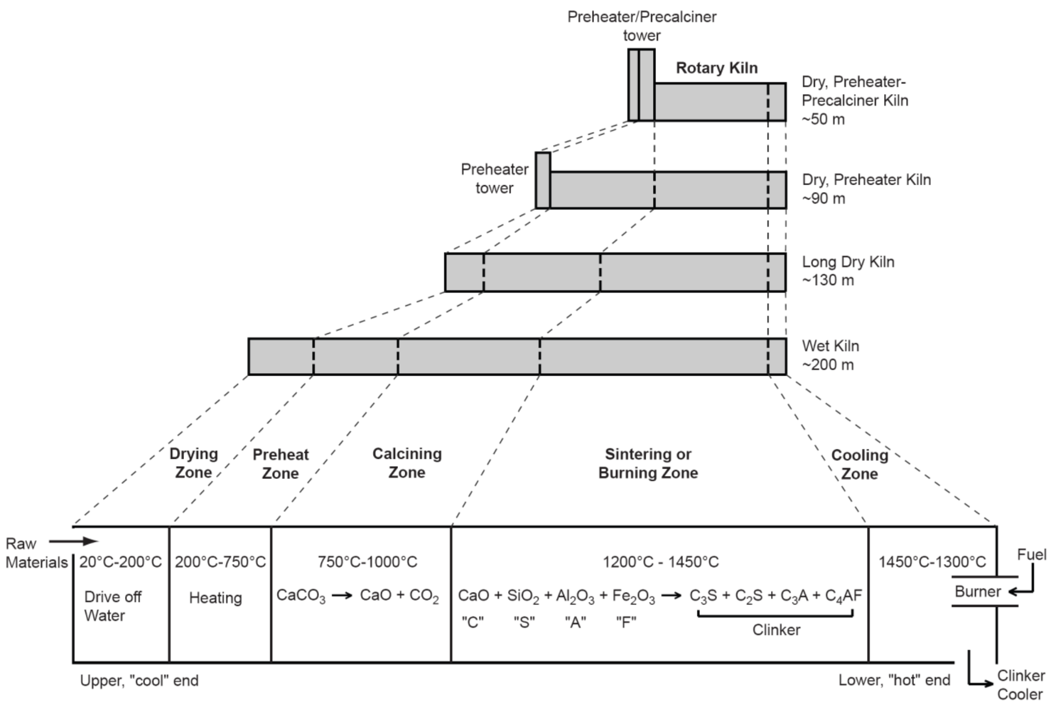
13. Portland cement production begins with the manufacture of clinker followed by its fine grinding with gypsum and other additives to make the finished cement product. Grinding can occur on site or at offsite grinding plants known as cement mills. Clinker manufacture involves the quarrying, crushing, and proportioning of raw materials to produce either a raw meal for the dry and semi-dry processes or a slurry for the wet and semi-wet processes. Once the material is prepared, the raw mix is fed into a kiln where it is heated as it moves through a number of chemical and physical processes necessary for forming the clinker.

14. In the kiln, the raw meal, or slurry in the wet process, is subjected to a thermal treatment process consisting of the consecutive steps of ‘drying/preheating’, ‘calcining’, and ‘sintering’ (also known as ‘burning’ or ‘clinkering’); the various reactions zones are depicted in **Figure 1A**.

15. The first drying and preheating zone, occurs in a temperature range of from <100 to 750°C. Here, residual or free water is evaporated from the raw meal feed, the clay materials begin to decompose and the bound water is removed so that they become dehydrated. Next is the calcining zone, where materials temperatures range from 750 to 1000°C. The material is ‘calcined’, where the calcium carbonate ($CaCO_3$) in the limestone is dissociated producing calcium oxide (CaO, lime) and liberating carbon dioxide (CO_2) gas.

16. Finally, in the burning zone, calcium oxide reacts with silicates, iron, and aluminium to form dicalcium silicate, tricalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite, denoted in shorthand as C_2S, C_3S, C_3A, and C_4AF respectively. In addition, clinker nodules, typically 3 to 20 mm in diameter, are formed in a semi-solid state in the burning zone, and solidify completely on cooling, which begins in a short cooling zone within the kiln, and continues in a cooler, outside of the cement kiln.

Figure 1A - Diagram of 'reaction' zones for different kiln technologies



Source: van Oss (2005)

17. In the clinker burning process, it is essential to maintain kiln charge temperatures in the sintering zone between 1400 and 1500°C to convert the raw meal to clinker. To reach these temperatures, flame temperatures of about 2000°C are necessary. Also, for reasons of clinker quality, excess air is required in the sintering zone to maintain oxidizing conditions. Otherwise, if insufficient oxygen is present, tetracalcium alumino ferrite does not form; instead Fe_2O_3 is reduced to FeO. This leads to a clinker product that produces a quick setting cement with decreased final strength. Additionally, the presence of unburned carbon in the burning region produces a clinker with an undesirable brown colour. (U.S. EPA, 2004)

18. The composition of the clinker, as well as the names and formulas of the clinker components are listed in **Table 1E**.

19. To complete the production of Portland cement, the cooled clinker is ground with a small amount of gypsum or anhydrite. **Figure 1 Figure 2** in the main Guidelines provides a process flow diagram of the general cement manufacturing process.

TABLE 1E - TYPICAL MINERALOGICAL COMPOSITION OF ORDINARY PORTLAND CEMENT CLINKER

Chemical name (common name)	Chemical formula	Common notation a/	Concentration range
Tricalcium silicate ('alite')	Ca_3SiO_5	C_3S	50-70%
Dicalcium silicate ('belite')	Ca_2SiO_4	C_2S	15-30%
Tricalcium aluminate ('aluminate')	$Ca_3Al_2O_6$	C_3A	5-10%
Tetracalcium aluminoferrite ('ferrite')	$Ca_4Al_2Fe_2O_{10}$	C_4AF	5-15%

a/ Abbreviations: C=CaO; S=SiO_2; A=Al_2O_3; F=Fe_2O_3
Source: Taylor (1997)

20. Clinker can be made either in energy-intensive and small-scale vertical kilns or in more efficient, larger scale rotary kilns. With the exception of vertical shaft kilns (VSK) still used in certain geographical areas (mainly China and India) (CPCB, 2007; Höhne and Ellermann, 2008), cement clinker is predominantly burnt in rotary kilns. For the manufacture of cement using rotary kilns, heating of the raw meal to produce cement clinker can take place in one of four different types of arrangements: the 'dry', 'semi-dry', 'semi-wet', or 'wet' processes (EIPPCB, 2010; UNEP, 2007):

(a) Dry process: Dry raw meal is fed to a cyclone preheater or precalciner kiln or, in some cases, to a long dry kiln with internal chain preheater.
(b) Semi-dry process: Dry raw meal is pelletised with water and fed to a travelling grate preheater prior to the rotary kiln or in some cases, to a long kiln equipped with internal cross preheaters.
(c) Semi-wet process: Raw slurry is first dewatered in filter presses. The resulting filter cake is either extruded into pellets and fed to a travelling grate preheater or fed directly to a filter cake drier for (dry) raw meal production prior to a preheater/precalciner kiln.
(d) Wet process: The raw slurry is fed either directly to a long rotary kiln equipped with an internal drying/preheating system (conventional wet process) or to slurry drier prior to a preheater/precalciner kiln (modern wet process).

21. In China, approximately 60 % of the cement was produced in 2005 in VSKs, an amount that is expected to drop to 50 % by 2015 (Karstensen, 2006a). In Europe, about 90 % of the cement production is from dry process kilns, a further 7.5 % of production is accounted for by semi-dry and semi-wet process kilns, with the

remainder of European production, about 2.5 per cent, coming from wet process kilns (EIPPCB, 2010). In the United States, no new wet kilns have been built since 1975, and approximately 80 % of U.S. cement production capacity now relies on the dry process technology (U.S. E P A, 2007). The wet process remains dominant in the former Soviet Union and Australia/New Zealand and is still significant in Canada, India, Latin America and Africa (Watson et al., 2005). **Table 1F** provides the share mix of kiln technologies in each region or country in 2002.

TABLE 1F - SHARE OF DIFFERENT KILN TYPES IN 2002

Regions, Countries		Kiln Type (% Production)			
		Dry	Semi-Dry	Wet	Vertical
North America	United States	65	2	33	0
	Canada	71	6	23	0
Western Europe		58	23	13	6
Eastern Europe	Former Soviet Union	12	3	78	7
	Other Eastern Europe	54	7	39	0
Asia	Japan	100	0	0	0
	Australia and New Zealand	24	3	72	0
	China	5	0	2	93
	South East Asia	80	9	10	1
	Republic of Korea	93	0	7	0
	India	50	9	25	16
Latin America		67	9	23	1
Africa		66	9	24	0
Middle East		82	3	16	0

Source: Baron et al. (2007)

22. Although VSKs are improvements over the old, chimney-type kilns in that some VSKs allow for continuous processing, they are considered to be less energy efficient than the rotary kilns, and VSK clinker (and hence cement) is generally considered to be of lower quality (van Oss, 2005). Furthermore, many VSKs plants have virtually no environmental controls in place, and the nature of the technology precludes effective use of modern dust (and other emission) controls. Compared with preheater/precalciner kilns, VSKs seems to consume from 14 to 105 % more coal per tonne of clinker; fuel substitution is however not feasible for vertical shaft kilns (Karstensen, 2006a). The raw materials used for cement production in VSKs are exactly the same as in any other production process; corrective materials may also be required to adjust the chemical composition of the raw mix.

ANNEX 2

QUALITY ASSURANCE AND QUALITY CONTROL PROGRAM IN THE IMPLEMENTATION OF CO-PROCESSING IN CEMENT PLANT

ANNEX 2 – QUALITY ASSURANCE AND QUALITY CONTROL PROGRAM IN THE IMPLEMENTATION OF CO-PROCESSING IN CEMENT PLANT

1. A comprehensive programme for quality assurance (QA) and quality control (QC) should be applied. The aim is to ensure that the product meets standard specifications, plant operations are not negatively affected by the use of hazardous wastes, environmental protection and to reduce health and safety risks. QA is necessary for ensuring that all data and the decisions resulting from that data are technically sound, statistically valid, and properly documented.

2. A QA plan should be prepared to help ensure that the monitoring, sampling, and analytical data meet specific objectives for precision, accuracy, and completeness and to provide the framework for evaluating data quality. The plan should cover waste streams and product materials handled at the facility with detailed instructions for the following:

   (a) Organization and responsibilities;
   (b) QA objectives for data measurement of precision, accuracy, completeness, representativeness, and comparability;
   (c) Sampling procedures;
   (d) Sample handling and custody;
   (e) Analytical procedures;
   (f) QC checks (blanks, spikes, replicates, etc.) and frequency;
   (g) Instrument/equipment testing, inspection, or maintenance;
   (h) Instrument/equipment calibration procedures and frequency;
   (i) Data review, verification, validation, and reporting.

3. Adequate laboratory design, infrastructure, equipment, and instrumentation should be provided and maintained to ensure that all required analysis are completed in a timely manner. Periodic tests of the laboratory should be considered to evaluate and improve performance.

4. Safety and health should be taken into consideration when conducting sampling. Employees carrying out sampling require training for the hazards associated with waste, handling procedures, protective clothing and equipment. Those involved in sampling activities should be fully aware of applicable QA/QC procedures.

5. BAT for waste quality control in cement manufacturing processes is outlined by the EIPPCB (2010):

   (a) To apply QA systems to guarantee the characteristics of wastes and to analyse any waste that is to be used as raw material and/or fuel in a cement kiln for: maintenance of quality over time; physical criteria, for example, emissions formation, coarseness, reactivity, burnability, calorific value; chemical criteria, for example, chlorine, sulphur, alkali and phosphate content and relevant metals content;

(b) To control the amount of relevant parameters for any waste that is to be used as raw material and/or fuel in a cement kiln, such as chlorine, relevant metals (for example, cadmium, mercury, thallium), sulphur, total halogen content;

(c) To apply QA systems for each waste load.

6. Internal audits should be carried out with a frequency that ensures QA/QC procedures are in use and that personnel conform to them. Independent third party audits should be conducted at least annually or as required to determine the effectiveness of the implemented quality system. Audit reports should be submitted to management with requirements to correct observed deficiencies.

ANNEX 3

HEALTH AND SAFETY ASPECTS

ANNEX 3 – HEALTH AND SAFETY ASPECTS

1. Health and safety should be a conscious priority and integrated into all aspects of operations during hazardous waste management. Overall and specific personnel requirements, the chain of command, and individual roles and responsibilities, should be clearly established.

2. A health and safety programme should be designed to identify, evaluate, and control safety and health hazards, and provide for emergency response for hazardous waste operations. The content and extent of this programme should be proportionate to the types and degrees of hazards and risks associated with specific operations.

3. Adequate documentation and information on safe hazardous waste handling, operating procedures and contingency measures should be available. Through openness and transparency, facility management should ensure the workforce is fully informed about health and safety measures and standards. Easily understood safety and emergency instructions should be provided to employees and contractors in advance.

4. In the EU, the BAT includes the appliance of hazardous waste safety management to the handling, storage, and the feeding of hazardous waste materials. For example, using a risk based approach according to the source and type of waste, for the labelling, checking, sampling and testing of waste to be handled. (EIPPCB, 2010)

Hazard analysis

5. Hazards and potential exposures should be determined and appropriate controls should be in place to maintain employee health and safety. Hazards requiring the use of personal protective equipment (PPE) should be identified. Assessments such as job hazard analysis (JHA), job safety analysis (JSA), safety analysis reports (SAR), process hazard analysis (PHA), and job, task, and hazard analysis (JTHA), are recommended.

Access and hazard control

6. To eliminate or control worker exposure to hazards, the following should be considered in order of preference:

   (a) Engineering controls to preclude worker exposure by removing or isolating the hazard. For example, ventilation or use of remotely operated material handling equipment;

   (b) Administrative controls to manage worker access to hazards and establish safe working procedures. For example, security measures to prevent unauthorized or unprotected access to hazardous wastes on-site;

(c) PPE, when engineering or administrative controls are not feasible or do not totally eliminate the hazard.

7. These controls are designed to reduce and maintain employee exposure below national occupational exposure limit values. If these are not available, internationally recognized exposure levels should be considered.

8. Examples include: the Threshold Limit Value (TLV) occupational exposure guidelines by the American Conference of Governmental Industrial Hygienists (ACGIH); the Pocket Guide to Chemical Hazards by the United States National Institute for Occupational Health and Safety (NIOSH); Permissible Exposure Limits (PELs) by the Occupational Safety and Health Administration of the United States (OSHA); Indicative Occupational Exposure Limit Values (IOELVs) by European Union member states, or other similar sources.

9. For hazardous substances and health hazards for which there are no permissible or applicable exposure limits, the operators could use the published literature and material safety data sheets (MSDS) as a guide to determine an appropriate level of protection.

Personal protective equipment

10. Employees, contractors and visitors to an installation should be provided with PPE where engineering control methods are not feasible to reduce exposure to permissible exposure limits. PPE should be selected to protect against any present or potential hazard and appropriate to the task-specific conditions and duration.

11. All personnel involved in hazardous waste operations should be fully aware of: equipment selection and use, maintenance and storage, decontamination and disposal, training and proper fit, donning and doffing procedures, inspection, in-use monitoring, programme evaluation, and equipment limitations.

Training

12. Employees should be effectively trained to a level determined by their job function and responsibility. This should be carried out prior to them being permitted to engaging in hazardous waste operations that could expose them to hazardous substances, safety, or health hazards. Training activities should be adequately monitored and documented in terms of curriculum, duration, and participants.

13. The training should cover safety, health and other hazards present on the facility; use of personal protective equipment; work practices to minimize risks from hazards; safe use of engineering controls and equipment on the site; medical surveillance, including recognition of symptoms and signs that could indicate over exposure to hazards. Those engaged in hazardous emergency response should also be appropriately trained.

Medical surveillance

14. A medical monitoring programme should be implemented to assess and monitor employee health both prior and during employment. An effective programme should consider the following components as a minimum:

(a) Pre-employment screening, to determine fitness-for-duty, including the ability to work while wearing PPE, and provide baseline data for future exposures;

(b) Periodic medical monitoring examinations (the content and frequency of which depend on the nature of the work and exposure), to determine biological trends that may mark early signs of chronic adverse health effects;

(c) Provisions for emergency and acute non-emergency treatments.

Emergency response

15. Emergency plans and procedures should be established for the protection of the workforce and public before hazardous waste operations begin. An Emergency Response Plan, ensuring appropriate measures to handle possible on-site emergencies and coordinate off-site response, should be in place. As a minimum, this plan should address the following:

(a) Pre-emergency planning and coordination with outside emergency responders;
(b) Personnel roles, lines of authority, training and communication procedures;
(c) Emergency recognition and prevention procedures;
(d) Safe distances and places of refuge;
(e) Site security and control procedures;
(f) Evacuation routes and procedures;
(g) Site mapping highlighting hazardous areas, site terrain, site accessibility and off-site populations or environments at potential risk;
(h) Decontamination procedures;
(i) Emergency medical treatment and first aid procedures;
(j) Personal protective and emergency equipment at the facility;
(k) Emergency alerting and response procedures;
(l) Documenting and reporting to local authorities;
(m) Critique of response and follow-up procedures.

16. Emergency equipment, such as fire extinguishers, self-contained breathing apparatus, sorbents and spill kits, and shower/eye wash stations should be located in the immediate vicinity of hazardous waste storage and processing areas.

17. The Plan procedures should be rehearsed regularly using drills and mock situations, and reviewed periodically in response to new or changing conditions or information.

18. Arrangements should be made to familiarize local authorities and emergency responders with the layout of the facility; properties of hazardous waste handled at the facility and associated hazards; places where facility personnel would normally be working; facility entrances and possible evacuation routes. Arrangements agreed to by local authorities, hospitals and emergency response teams should be described in the Emergency Response Plan.

ANNEX 4

COMMUNICATIONS AND STAKEHOLDER INVOLVEMENT

ANNEX 4 – COMMUNICATIONS AND STAKEHOLDER INVOLVEMENT

1. Stakeholders are those who see themselves as potentially affected by the operations of a facility. These can be individuals and groups on a local, national, or international scale and include neighbours, community organizations, employees, trade unions, government agencies, the media, non-governmental organizations, contractors, suppliers and investors.

2. Public communication is the providing of information through media sources, including brochures, websites, newspapers, radio and television. Stakeholder involvement is concerned with community members and others with an interest in the facility, through public meetings, presentations, advisory committees, and personal approaches. Both should form part of the normal operations of a plant.

3. Facilities should have clear objectives for working with stakeholders. This includes a realistic timescale for engagement, committing necessary resources and a willingness to find mutually beneficial outcomes.

4. Operators and regulatory authorities should be prepared to address public concerns over possible impacts of co-processing and strive to establish efficient communication methods to explain the activities. Operators planning on using hazardous waste should provide all necessary information to allow stakeholders to understand the use of the wastes in the cement kiln while illustrating the measures that would be implemented to avoid adverse impacts.

ANNEX 5

GENERAL RECOMMENDATION ON WASTE ACCEPTANCE AND PRE-PROCESSING OF HAZARDOUS WASTE FOR CO-PROCESSING

ANNEX 5 – GENERAL RECOMMENDATION ON WASTE ACCEPTANCE AND PRE-PROCESSING OF HAZARDOUS WASTE FOR CO-PROCESSING

WASTE ACCEPTANCE

1. Prior knowledge of wastes is necessary to ensure that the waste falls within the requirements of the facility's permit and will not adversely affect the process. Generators of hazardous waste should in most circumstances know the composition, nature and problems associated with their waste, ensuring that all relevant information is passed to those involved in its subsequent management.

2. Hazardous and non hazardous waste acceptance comprises two stages: pre-acceptance (or screening) and on-site acceptance. Pre-acceptance involves the provision of information and representative samples of the waste to allow operators to determine suitability before arrangements are in place for acceptance. The second stage concerns procedures when the waste arrives at the facility to confirm previously approved characteristics.

3. Failure to adequately screen waste samples prior to acceptance and a confirmation of its composition on arrival at the installation may lead to subsequent problems. Inappropriate storage, mixing of incompatible substances, and accumulation of wastes could occur.

Pre-acceptance

4. A pre-acceptance, or pre-shipment screening, protocol should ensure that only properly and safely handled hazardous waste streams are approved for shipment to the facility. Such protocol is necessary to:

   (a) Ensure regulatory compliance by screening out unsuitable wastes;
   (b) Confirm the details relating to composition, and identify verification parameters that can be used to test waste arriving at the facility;
   (c) Identify any substances within the waste that may affect its processing, or react with other reagents;
   (d) Accurately define the range of hazards exhibited by the waste.

5. The operator should obtain information on the nature of the process producing the waste, including its variability. Other required descriptions include: composition (chemicals present and individual concentrations); handling requirements and associated hazards; the quantity and the form of waste (solid, liquid, sludge etc); sample storage and preservation techniques. Ideally, information should be provided by the waste generators . Alternatively a system for the verification of the information provided by any intermediaries should be considered.

6. Systems for the provision and analysis of waste representative samples should be in place. The waste sample should be taken by a competent technician and the

analysis carried out by a laboratory, preferably accredited with robust QA/QC methods and record keeping and a chain-of-custody procedure should be considered. The operator should carry out a comprehensive characterisation (profiling) and testing with regard to the planned processing for each new waste. No waste should be accepted without sampling and testing being carried out. The exception is unused, outdated or off-specification uncontaminated products that have appropriate MSDS or product data sheets.

7. A Waste Analysis Plan (WAP) should be prepared and maintained to document procedures used to obtain a representative waste sample and to conduct a detailed chemical and physical analysis. A WAP should address measures used to identify potentially reactive and incompatible wastes. It should include testing of a representative sample to qualify the waste for use at the facility (pre-acceptance) and to verify its constituents (acceptance). Further testing of samples taken during or after waste pre-processing or blending should be used to verify the quality of the resultant stream.

8. Operators should ensure that the technical appraisal is carried out by qualified, experienced staff who understands the capabilities of the facility.

9. Records of pre-acceptance should be maintained at the facility for cross-referencing and verification at the waste acceptance stage. Information should be recorded and referenced, available at all times, regularly reviewed and kept up to date with any changes to the waste stream.

On-site acceptance

10. On-site verification and testing should confirm waste characteristics with the pre-acceptance information. Acceptance procedures should address:

    (a) Pre-approved wastes arriving on-site, such as a pre-booking system to ensure that sufficient capacity is available
    (b) Traffic control;
    (c) Check for documents arriving with the load;
    (d) Load inspection, sampling and testing;
    (e) Rejection of wastes and the discrepancy reporting procedures;
    (f) Record keeping;
    (g) Periodic review of pre-acceptance information.

11. Wastes should not be accepted without detailed written information identifying the source, composition and hazard levels.

12. Where facilities provide an emergency service such as the removal of spillages or fly-tipped hazardous wastes, there may be situations where the operator is unable to adhere to established pre-acceptance and/or acceptance procedures. In such instances, the operator should communicate the occurrence to the competent authorities immediately.

Arrival

13. If sufficient storage capacity exists and the site is adequately manned, suitably qualified and trained personnel should supervise the receiving of hazardous wastes. All wastes received should be treated as unknown and hazardous until compliance with specifications has been positively verified.

14. A suitable description should accompany hazardous waste delivery including: name and address of the generator; name and address of the transporter; waste classification and description; volume and weight; and hazardous characteristics of the waste.

15. Documentation accompanying the shipment should be reviewed and approved, including the hazardous waste manifest, if applicable. Any discrepancies should be resolved before the waste is accepted. If they cannot be resolved, the waste should be rejected and sent back to the original generator, or at its request, to an alternate facility.

16. Where possible, waste loads should be visually inspected. All containers should be clearly labelled in accordance with applicable regulations for the transport of dangerous goods and checked to confirm quantities against accompanying documentation. They should be equipped with well-fitting lids, caps and valves secure and in place and inspected for leaks, holes, and rust. Any damaged, corroded or unlabelled container or drum should be classified as 'non-conforming' and dealt with appropriately.

17. All incoming loads should be weighed, unless alternative reliable volumetric systems linked to specific gravity data are available.

Inspection

18. Wastes should only be accepted at the facility after thorough inspection. Reliance solely on supplied written information should not be acceptable. Physical verification and analytical confirmation should be undertaken to ensure the waste meets permit specifications and regulatory requirements. All wastes, whether for processing or storage, should be sampled and undergo verification and testing, according to the frequency and protocol defined in the WAP, except for unused, outdated, off-specification or uncontaminated products.

19. On-site verification and testing should take place to confirm:

    (a) The identity and description of the waste;
    (b) Consistency with pre-acceptance information;
    (c) Compliance with the facility permit.

20. Techniques for inspection vary from simple visual assessment to full chemical analysis. The extent of the procedures adopted will depend upon waste chemical and physical composition and variation; known difficulties with certain waste types

or of a certain origin; specific sensitivities of the installation concerned (for example, certain substances known to cause operational difficulties); and the existence or absence of a quality controlled specification for the waste, among others. (Karstensen, 2008a)

21. The facility should have a designated sampling or reception area where containerised waste is unloaded if adequate space is available and temporarily stored for further sampling and sample analysis. Wastes should be segregated immediately to remove possible hazards due to incompatibility. Sampling should ideally take place within 24 hours of unloading. During this period, hazardous wastes should not be bulked, blended or otherwise mixed. Bulk wastes should be inspected and accepted for processing prior to unloading.

22. Sampling should comply with specific national legislation, where it exists, or with international standards. Sampling should be supervised by laboratory staff and in those countries where regulations do not exist, qualified staff should be appointed. Sampling should include well-established procedures such as those developed by the American Society for Testing and Materials (ASTM), the European Committee for Standardization (CEN), and the United States Environmental Protection Agency (EPA). A record of the sampling regime for each load and justification for the selected option should be maintained.

23. Samples should be analysed by a laboratory with a robust QA/QC programme, including but not limited to suitable record keeping and independent assessments. Analysis should be carried out at a timescale required by facility procedures. In the case of hazardous wastes this often requires the laboratory to be on-site.

24. Typically, waste should be sampled and analysed for a few key chemical and physical parameters (fingerprint analysis) to substantiate the waste composition designated on the accompanying manifest or other documents. The selection of key parameters must be based on sufficient waste profile knowledge and testing data to ensure accurate representation. When selecting fingerprint parameters, consideration should be given to those that: identify unpermitted wastes; determine suitability within the facility's operational acceptance limits; identify potential reactivity or incompatibility; indicate any changes in composition that had occurred during transportation or storage. Should fingerprint testing results of a given waste stream fall outside the established tolerance limits, the waste may be re-evaluated for possible acceptance to prevent the unnecessary movement of waste back and forth between the generator and the installation. Re-evaluation should consider facility conditions for storage and processing; additional parameter analysis deemed appropriate by the operator and established in the WAP; permit requirements.

25. The inspection scheme may include: assessment of combustion parameters; blending tests on liquid wastes prior to storage; control of flashpoint; and screening of waste input for elemental composition, for example by ICP, XRF and/or other appropriate techniques, in accordance to waste types and characteristics, and the facility waste acceptance criteria. (Karstensen, 2008a)

26. Wastes should be moved to the storage area only after acceptance. Should the inspection or analysis indicate a failure to meet the acceptance criteria, including damaged or unlabelled drums, such loads should be stored in a quarantine area, allocated for non-conforming waste storage, and dealt with appropriately.

27. All areas where hazardous waste is handled should have an impervious surface with a sealed drainage system. Attention should be given to ensuring that incompatible substances do not come into contact resulting from spills from sampling, for example, within a sump serving the sampling point. Absorbents should be available.

28. In accordance with national legislation and practice, suitable provisions should be made to verify that wastes received are not radioactive, such as the use of plastic scintillation detectors.

29. After acceptance, containerised hazardous waste should be labelled with the arrival date and primary hazard class. Where containers are bulked, the earliest arrival date of the bulked wastes should be indicated on the bulk container. Each container should be given a unique reference number for in-plant tracking.

Non-conforming waste

30. The operator should have clear and unambiguous criteria for the rejection of wastes, including wastes that fail to meet the acceptance criteria, and damaged, corroded or unlabelled drums. A written procedure for tracking and reporting such non-conformance should include notification to the customer or waste generator and competent authorities.

31. The operator should also have a clear and unambiguous policy for the subsequent storage, including a maximum storage volume, and disposal of rejected wastes. This policy should achieve the following:

    (a) Identify the hazards posed by the rejected wastes;
    (b) Label rejected wastes with all information necessary to allow proper storage and segregation arrangements to be put in place;
    (c) Segregate and store rejected wastes safely pending removal within no more than five working days, where possible.

32. Wastes not fulfilling the acceptance criteria of the plant should be sent back to the waste generator, unless an agreement is reached with the generator to ship the rejected waste to an alternative authorised destination.

In-plant tracking system

33. An internal wastes tracking system and stock control procedure should be in place, starting at the pre-acceptance stage, to guarantee the traceability of waste processing and enabling the operator to:

(a) Prepare the most appropriate waste blend;
(b) Prevent unwanted or unexpected reactions;
(c) Ensure that the emissions are either prevented or reduced;
(d) Manage wastes throughput.

34. The tracking system, which may be a paper-based, electronic, or a combination of both), should trace the waste during its acceptance, storage, processing and removal off-site. At any time, the operator should be able to identify the location of a specific waste on the facility and the length of time it has been there. Records should be held in an area removed from hazardous activities to ensure their accessibility during any emergency.

35. Once a waste has entered bulk storage or a treatment process, tracking individual wastes will not be feasible. However, records should be maintained to ensure sufficient knowledge is available as to what wastes have entered a particular storage facility. For example, to avoid incompatibility with incoming wastes, it is necessary to keep track of residues building up within a vessel between de-sludging operations.

36. For bulk liquid wastes stock control should involve maintaining a record of the route through the process. Waste in drums should be individually labelled to record the location and duration of storage.

37. The in-plant waste tracking system should hold a complete record generated during pre-acceptance, acceptance, storage, processing and removal off-site. Records should be kept up to date to reflect deliveries, on-site treatment and dispatches. The tracking system should operate as a waste inventory, stock control system and include as a minimum:

(a) A unique reference number;
(b) Details of the waste generator and intermediate holders;
(c) Date of arrival on-site;
(d) Pre-acceptance and acceptance analysis results;
(e) Container type and size;
(f) Nature and quantity of wastes held on-site, including identification of associated hazards;
(g) Details on where the waste is physically located;
(h) Identification of staff who have taken any decisions on acceptance or rejection of wastes.

38. The system adopted should be structured to report on:

(a) Total quantity of waste present on-site at any one time, in appropriate units;
(b) Breakdown of waste quantities being stored pending on-site processing;
(c) Breakdown of waste quantities on-site for storage only, that is, awaiting transfer;
(d) Breakdown of waste quantities by hazard classification;
(e) Indication of where the waste is located relative to a site plan;
(f) Comparison of the quantity on-site against total permitted;
(g) Comparison of time the waste has been on-site against permitted limit.

WASTE STORAGE AND HANDLING

39. After deciding the waste's suitability, the operator should have systems and procedures in place for transfer to appropriate storage safely.

40. Considerations for waste storage on the installation should include:

(a) Location of storage areas;
(b) Storage area infrastructure;
(c) Condition of tanks, drums, vessels and other containers;
(d) Stock control;
(e) Segregated storage;
(f) Site security;
(g) Fire risk.

<u>Design considerations</u>

41. Transfer and storage areas should be designed to handle accidental spills. This may require that:

(a) To prevent spills from spreading or seeping into the soil, storage areas should have adequate boundaries and be adequately sealed, impermeable and resistant to the stored waste materials;
(b) All spills should be collected, placed in a suitable container, and stored for disposal in the kiln;
(c) If a spill occurs, incompatible wastes should be prevented from mixing;
(d) All connections between tanks should be capable of being closed by valves. Overflow pipes should be directed to a contained drainage system such as a bounded area or another vessel;
(e) Leak free equipment and fittings should be installed whenever possible;
(f) Measures to detect leaks and appropriate corrective action should be provided;
(g) Contaminated runoff should be prevented from entering storm drains and watercourses. Any runoff should be collected and stored for disposal in the kiln;

(h) Adequate alarms for abnormal conditions should be provided.

42. Storage design should be appropriate to maintain waste quality for the complete storage period. Segregated storage should be in place to prevent incidents from incompatible wastes and as a means of preventing escalation should an incident occur. Individual storage requirements on a particular installation will be dependent on a full assessment of risk.

43. Within the facility, specific storage area characteristics should reflect the properties of the waste that poses the greatest risk that can be accepted. In general, the storage criteria should also take into account the unknown nature and composition of wastes, as this gives rise to additional risks and uncertainties. In many cases, this uncertainty means that higher specification storage systems are applied for wastes than for well-characterised raw materials.

44. Containerised wastes should be stored under cover, protected from heat, direct sunlight and rain, unless the waste is known to be unaffected by such ambient conditions.

45. For containerised wastes, the design should be such to prevent accumulation of hazardous wastes beyond the allowable storage timescale. For liquid wastes, mixing or agitation to prevent settling of solids should be considered. It may be necessary to homogenise tank contents with mechanical or hydraulic agitators. Depending on the waste characteristics, some tanks may need to be heated and insulated.

46. The construction, material selection and design of equipment, such as tanks, pipelines, valves, and seals should be appropriate for the characteristics of the waste. They should be sufficiently corrosion proof, and offer the option of cleaning and sampling.

47. Adequate ventilation should be provided in consideration to applicable work exposure guidelines. Periodic monitoring should be considered for open stored wastes that may emit VOC.

48. A fire protection system approved by local authorities, for example, a local fire department, should be in place. Automatic fire detection systems should be used in waste storage areas as well as for fabric filters and electrostatic precipitators (ESP), electrical and control rooms, and other identified risk areas. Continuous, automatic temperature measurement of the surface of wastes in the storage pits can be used to trigger an acoustic alarm to indicate temperature variations.

49. Automatic fire suppression systems should be used when storing flammable liquid waste and in other risk areas. Foam and carbon dioxide control systems provide advantages in some circumstances, for example, for the storage of flammable liquids. Water systems with monitors, water cannons with the option to use water or foam, and dry powder systems are commonly used.

Operational considerations

50. Written procedures and instructions for the unloading, handling, and storage of wastes on-site should be in place. It should be ensured that chemically incompatible wastes are segregated. Compliance should be audited regularly.

51. To avoid the need for additional handling and transfer hazardous wastes should be stored in the same containers (drums) that were used for delivery.

52. Designated routes for vehicles carrying specific hazardous wastes should be clearly identified within the facility. On-site transportation should minimize risk to the health and safety of employees, the public and the environment. The operator should ensure that vehicles are fit for purpose with respect to compliance with relevant regulations.

53. All loads should be properly identified, segregated according to compatibility (so that any potential spills do not create chemical safety hazards), and secured to prevent sliding or shifting during transport. Personnel should be directed and trained to use equipment only as intended, and not to exceed the rated capacity of containers, vehicles, and other equipment.

54. Appropriate signage indicating the nature of hazardous wastes should be in place at storage, stockpiling, and tank locations.

55. Containers should be kept in good condition, free of dents, not leaking or bulging, and closed not in use. Container storage areas should have at least a weekly inspection.

56. Maintenance work should be authorized by plant management, and carried out after the area has been checked by a supervisor and all necessary precautions have been taken. Special procedures, instructions, and training should be in place for routine operations such as:

    (a) Working at heights, including proper tie-off practices and use of safety harnesses;
    (b) Confined space entry where air quality, explosive mixtures, dust, or other hazards may be present;
    (c) Electrical lock-out, to prevent accidental reactivation of electrical equipment undergoing maintenance;
    (d) ‘Hot works’ (welding, cutting, etc.) in areas that may contain flammable materials.

57. Safety measures that should be considered include:

    (a) Placing of uncontrolled combustible materials in storage areas should be avoided;
    (b) Where there is a risk that has not been avoided or controlled, standard safety signs and information signs should be in place;

(c) Emergency showers and eye wash stations should be provided within the work area for immediate emergency use following exposure to hazardous wastes. Consideration should be given to the possible need for multiple emergency shower installations, based upon access distance, and the possibility that more than one person may be affected at the same time;

(d) Adequate alarms should be provided to alert all personnel about emergency situations;

(e) On site communication equipment should be maintained so that in case of a fire, the control room and the local fire department can be contacted immediately;

(f) Electrical equipment should be earthed and have appropriate anti-static devices in place.

WASTE PRE-PROCESSING

58. So as not to detract from normal kiln operation, product quality, or the site's usual environmental performance, wastes used in cement kilns should be homogenous, with compatible particle size, stable chemical composition and heat content. For optimum operation, kilns require very uniform waste material flows in terms of quality and quantity. For certain types of wastes, this can only be achieved by pre-processing.

59. Pre-processing includes drying, shredding, grinding or mixing depending on the type of waste. It is usually carried out in a purpose-made facility, which may be located outside or inside the cement plant.

60. Liquid waste fuels are normally prepared by blending different products with suitable calorific values and chemistry, such as spent solvents or used oil. Only simple pre-treatment is usually necessary, such as the removal of bottoms, sediments and water. In some cases, for example machining oil/emulsion, chemical processes are necessary to remove metallic pollutants and additives. The extent of solid waste processing, such as sorting, crushing, or pelletizing, depends on the specific application.

Design considerations

61. Facility layout should be carefully considered to ensure access for day-to-day operations, emergency escape routes, and maintainability of the plant and equipment.

62. Recognized standards should be applied to the design of installations and equipment. Any modifications should be documented.

63. Health and safety assessments should be undertaken on operations to ensure equipment safety and to minimize risks of endangering people or installations, or damaging the environment. Appropriate procedures should be used to assess risks or hazards for each stage of the design process. Only competent and

qualified personnel should undertake or oversee such hazard and operating studies.

Operational considerations

64. Although mixing and homogenisation of wastes can improve feeding and combustion behaviour, it can involve risks and should be carried out according to a prescribed preparation.

65. Techniques used for waste pre-processing and mixing are wide ranging, and may include:

(a) Mixing and homogenising of liquid wastes to meet input requirements, for example, viscosity, composition and/or heat content;
(b) Shredding, crushing, and shearing of packaged wastes and bulky combustible wastes;
(c) Mixing of wastes in a storage pit or similar enclosure using a grab or other machine.

66. Crane operators should be capable of identifying potentially problematic loads, for example, baled wastes and discrete items that cannot be mixed or may cause loading and feeding problems. These can then be removed, shredded or directly blended (as appropriate) with other wastes.

67. General tidiness and cleanliness should be applied to enhance working environment and to allow potential operational problems to be identified in advance. The main elements are:

(a) Systems to identify, locate and store wastes received according to their risks;
(b) The prevention of dust emissions from operating equipment;
(c) Effective wastewater management;
(d) Effective preventive maintenance.

PRE-PROCESSING PLANT CLOSURE/DECOMMISSIONING

68. Closure is the period directly after the facility stops normal operations. During this period the facility stops accepting hazardous waste; completes storage and processing of any wastes left on site; and disposes or decontaminates equipment, structures, and soils, restoring the site, insofar as possible, to its original condition or in keeping with the intended land use. Planning for decommissioning of the facility should be undertaken during the initial stages of the overall project. By integrating decommissioning requirements into the facility design at the outset, the site development plan should be compatible with the proper closure requirements when the operation of the facility has ended.

69. Operators should be required to properly close the facility in a manner that minimizes the further need for maintenance, and prevents the escape of any hazardous contaminants to the environment. To ensure this, a closure plan should be prepared identifying the steps necessary to partially or completely close the facility, including:

(a) Procedures for handling removed inventory;
(b) Procedures for decontamination and/or disposal;
(c) Procedures to confirm effectiveness of decontamination, demolition and excavation, including procedures for performing sample collection and analysis;
(d) Health and safety plan addressing all health and safety concerns pertinent to closure activities;
(e) Security system to prevent unauthorized access to the areas affected by closure activities.

70. To prevent a facility from ceasing operations and failing to provide for the potentially costly closure requirements, operators should be required to demonstrate that they have the financial resources to properly conduct closure in a manner that protects both human health and the environment.

71. To minimise decommissioning problems and associated environmental impacts, it is recommended for existing installations, where potential problems are identified, to put in place a programme of design improvements (EIPPCB, 2006). These design improvements should ensure that underground tanks and piping are avoided. If replacement is not possible operators should provide secondary containment or develop a suitable monitoring programme. A procedure for the draining and cleaning out of vessels and piping prior to dismantlement, among others, should also be provided.

OTHER ENVIRONMENTAL ASPECTS

Volatile organic compounds, odours and dust

72. Emissions to air from waste pre-processing will depend on the types of wastes treated and the processes used. Emission monitoring and reporting should be performed according to operating permits and applicable regulations.

73. Abatement techniques should be in place as required and countermeasures for noise and odours considered. Dust is usually reduced by bag filters while VOC emission control technologies, if needed, may include carbon adsorption, thermal or biological treatments, among others.

74. In the EU, BAT is to apply the following techniques to prevent or control the emissions of dust, odours and VOC in the waste treatment sector as a whole: restrict the use of open topped tanks, vessels and pits; use an enclosed system with extraction to suitable abatement plant; apply a suitably sized extraction system; correctly operate and maintain the abatement equipment; have leak

detection and repair procedures in place; and reduce air emissions by using a suitable combination of preventive and/or abatement techniques (EIPPCB, 2006).

Drums and ferrous metals

75. Empty drums and ferrous metals removed by magnetic separators should be disposed of in an environmentally sound manner. Scrap metal not contaminated by chemicals or scheduled wastes can be recycled for steelmaking. Empty waste drums contaminated by chemicals or scheduled wastes in good condition can be sent to authorised/licenced drum washers/recyclers.

Wastewater

76. Discharges of wastewater to surface water should not result in contaminant concentrations in excess of local ambient water quality criteria, or in their absence, other recognized ambient water quality criteria. Receiving water use and assimilative capacity, taking other sources of discharges to the receiving water into consideration, should also influence the acceptable pollution loadings and effluent discharge quality.

77. Discharges into public or private wastewater treatment systems should meet the pre-treatment and monitoring requirements of that sewer treatment system. It should not interfere, directly or indirectly, with the operation and maintenance of the collection and treatment systems, or pose a risk to worker health and safety, or adversely impact characteristics of residuals from wastewater treatment operations.

78. In the EU, BAT is to apply the following techniques to wastewater management in the waste treatment sector as a whole: reduce the water use and the contamination of water; avoid the effluent by-passing the treatment plant systems; collect spillages, drum washings, etc.; segregate the water collecting systems; have a concrete base in all the treatment areas; maximise the reuse of treated wastewaters; conduct daily checks on the effluent management system; carry out the appropriate treatment technique for each type of wastewater; achieve adequate water emission values before discharge by applying a suitable combination of techniques (EIPPCB, 2006).

EMISSIONS MONITORING AND REPORTING

79. Emissions and air quality monitoring programmes provide information that can be used to assess the effectiveness of relevant management strategies. A systematic planning process is recommended to ensure that data collected are adequate for the intended purposes and to avoid collecting data that are unnecessary. A monitoring programme for air quality should consider baseline monitoring to assess background levels of key pollutants both at and in the vicinity of the facility.

80. When wastewater is discharged, a monitoring programme, with adequate resources and management overview, for wastewater and water quality should be developed and implemented to meet set monitoring objectives.

81. The parameters selected for monitoring should be indicative of the pollutants of concern from the process, and should include parameters that are regulated under compliance requirements. Monitoring programmes should apply national or international methods for sample collection and analysis, such as those published by the International Organization for Standardization (ISO), CEN or the United States EPA. Sampling should be carried out or supervised by trained individuals. Those permitted or certified for this role should conduct the analysis. Sampling and analysis QA/QC plans should be applied and documented to ensure that data quality is adequate for the intended data use. Monitoring reports should include QA/QC documentation.

ANNEX 6

GENERAL RECOMMENDATION ON CO-PROCESSING OF HAZARDOUS WASTE

ANNEX 6 – GENERAL RECOMMENDATION ON CO-PROCESSING OF HAZARDOUS WASTE

OPERATIONAL REQUIREMENTS

1. Safe and responsible co-processing requires careful selection of the feed points in the kiln system as well as comprehensive operational control relating to the specific characteristics and volumes of the waste material.

Feed point selection

2. Adequate feed points should be selected according to relevant characteristics of the waste, including physical, chemical, and toxicological (see **Figure 6A**). Different feed points can be used, most commonly waste is introduced via:

   (a) The main burner at the rotary kiln outlet end;
   (b) A feed chute at the transition chamber at the rotary kiln inlet end (for lump fuel);
   (c) Secondary burners to the riser duct;
   (d) Precalciner burners to the precalciner;
   (e) A feed chute to the precalciner (for lump fuel);
   (f) A mid kiln valve in the case of long wet and dry kilns (for lump fuel).

3. Liquid wastes are typically injected into the hot end of the kiln. Solid wastes may be introduced into the calcining zone at some facilities. This is mid-kiln for long kilns, and onto the feed shelf in the high-temperature section for preheater/precalciner kilns.

4. Solid wastes used as alternative raw materials are typically fed into the kiln system via the normal raw meal supply, the same as traditional raw materials. However materials containing components that can be volatilised at low temperatures (for example, solvents) should be fed into the high temperature zones of the kiln system. Wastes containing volatile organic and inorganic components should not be fed via the normal raw meal supply unless controlled test runs in the kiln, or adequate laboratory tests, have demonstrated that undesired stack emissions can be avoided.

5. Combustible toxic compounds found in some hazardous waste, such as halogenated organic substances, need to be completely destroyed through proper temperature and residence time. In preheater/precalciner kilns, hazardous waste should generally be fed through either the main or the secondary burners. Hazardous and other wastes fed through the main burner, where conditions will always be favourable, decompose under oxidising conditions at a flame temperature of >1800°C (see **Figure 6B**). Waste fed to a secondary burner, preheater or precalciner will be exposed to lower temperatures, though expected burning zone temperatures in the precalciner are typically >1000°C (UNEP, 2007). The kiln should be operated in such a way that the gas resulting from the process is

raised, after the last injection of combustion air, in a controlled and homogeneous fashion and even under the most unfavourable conditions, to a temperature of 850 °C for two seconds (cf. Directive 2000/76/EC). In the case of hazardous wastes with a content of more than 1 per cent halogenated organic substances (expressed as chlorine), the temperature should be raised to 1100°C for at least two seconds.

FIGURE 6A - TYPICAL WASTE FEED POINTS

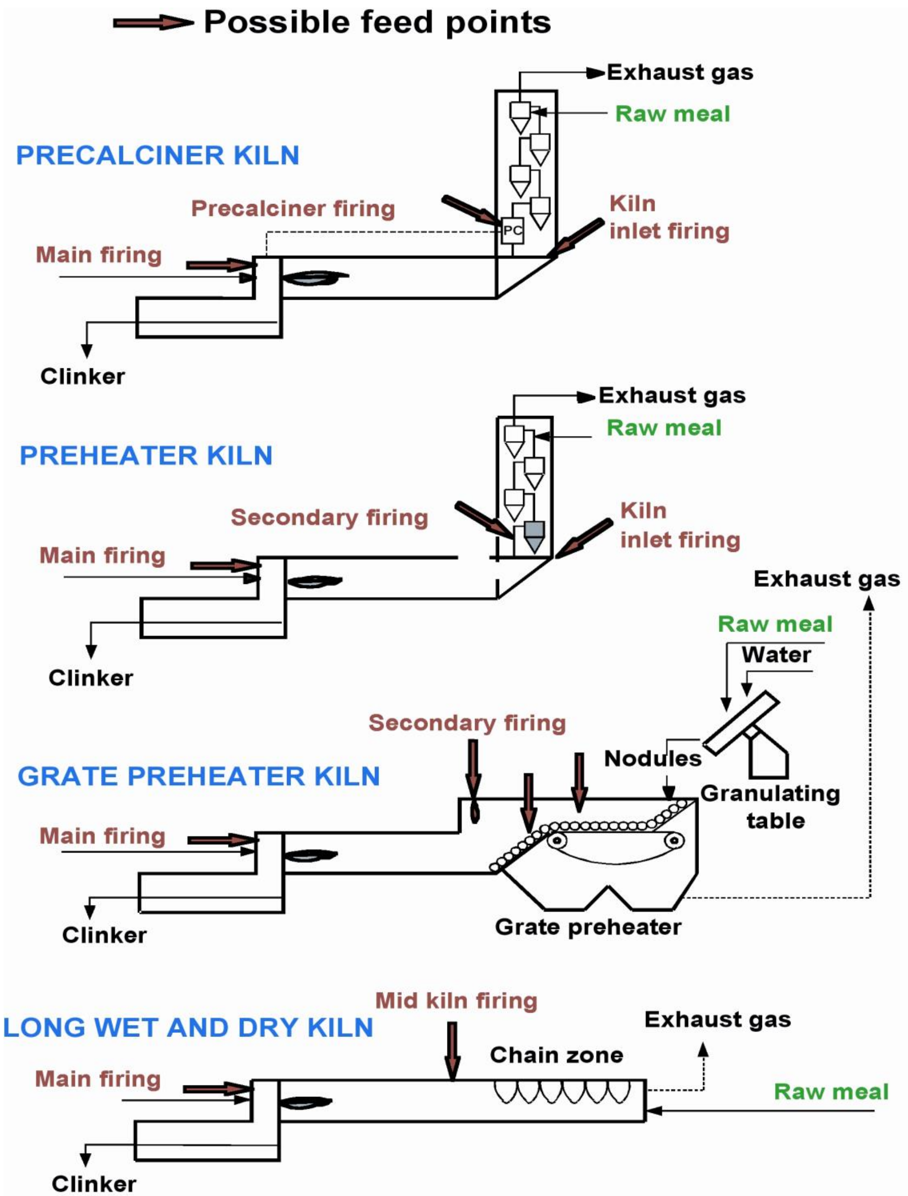
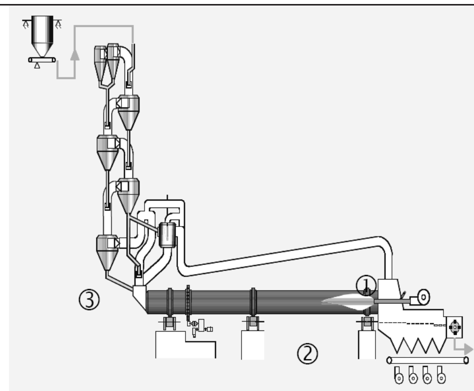


FIGURE 6B - TEMPERATURES AND RESIDENCE TIMES DURING CEMENT MANUFACTURE

Characteristics	Temperature and time
Temperature at main burner ① of the rotary kiln ②	>1450°C (material) >1800°C (flame temperature)
Residence time at main burner	>12-15 seconds > 1200°C >5-6 seconds > 1800°C
Temperature at precalciner ③	> 850°C (material) >1000°C (flame temperature)
Residence time at precalciner	> 2-6 seconds > 800°C



6. For hazardous waste feeding into the kiln, the following should be conducted (EIPPCB, 2010):

   (a) To use the appropriate feed points to the kiln in terms of temperature and residence time depending on kiln design and kiln operation;
   (b) To feed waste materials containing organic components that can be volatilised before the calcining zone into the adequately high temperature zones of the kiln system;
   (c) To operate in such a way that the gas resulting from the process is raised, in a controlled and homogeneous fashion and even under the most unfavourable conditions, to a temperature of 850 °C for 2 seconds;
   (d) To raise the temperature to 1100 °C, if hazardous waste with a content of more than 1 per cent of halogenated organic substances, expressed as chlorine, is fed into the kiln;
   (e) To feed wastes continuously and constantly;
   (f) To stop feeding waste when appropriate temperatures and residence times are not maintained or cannot be reached (at start-ups or shutdowns for instance), and whenever any emission limit value is exceeded.

Kiln operation control

7. To avoid operating problems within the kiln, the impact of hazardous waste on the total input of circulating volatile elements, such as chlorine, sulphur or alkalis, requires careful assessment prior to acceptance. Specific acceptance criteria for these components should be set by each facility based on the process type and on the specific kiln conditions.

8. The general principles of good operational control of the kiln system using conventional fuels and raw materials should also be applied to the use of waste. In particular, all relevant process parameters should be measured, recorded, and evaluated continuously. Kiln operators should undergo appropriate training for the requirements related to the use of hazardous waste, including health, safety, and environmental emission aspects.

9. For operational disruptions of the kiln, written work instructions describing the strategy to disconnect the hazardous waste feed to ensure minimum operational stability conditions should be available and known to the kiln operators.

10. The mineral content of the waste may affect the characteristics of the clinker. The raw mix composition should be adjusted accordingly to adhere to the given chemical set points. Input limits for chlorine, sulphur, and alkalis should be defined, and operational set points should be strictly observed. Bypass installations to avoid enrichment cycles of these compounds should only be considered if appropriate solutions for the management of the bypass dust generated have been identified.

11. It is important for combustion and process stability, for the purpose of controlling emissions of unintentionally formed POPs, to ensure (UNEP, 2007):

    (a) Consistency in fuel characteristics (both alternative and fossil);
    (b) Consistency in fuel supply rate or frequency of introduction of batch-charged materials;
    (c) That adequate excess oxygen is supplied to achieve good combustion;
    (d) That concentrations of CO in exhaust gases are monitored and do not exceed pre-established levels reflecting poor combustion conditions.

ENVIRONMENTAL ASPECTS

Air emissions

12. Whether or not wastes are being used in a cement plant, dust (particulate matter),NOx and SO2 emissions cause the greatest concern and needs to be dealt with. Other emissions to be considered are VOC, PCDDs, PCDFs, HCl, CO, CO2, HF, ammonia (NH3), benzene, toluene, ethylbenzene, xylene, polycyclic aromatic hydrocarbons (PAH), heavy metals and their compounds (EIPPCB, 2010). Under some circumstances, emissions may also include chlorobenzenes and PCBs (SBC, 2007).

13. Control technologies should be implemented by the cement plant to ensure compliance to the emission limit as outlined in these guidelines.

Cement kiln and bypass dust

14. All cement plants generate a fine dust from the kiln line, collectively labelled cement kiln dust (CKD). CKD composition varies, even over time from a single kiln line, but includes particulates representing the raw mix at various stages of burning, particles of clinker, and even particles eroded from the refractory brick and/or

monolithic linings of the kiln tube and associated apparatus (Van Oss, 2005). Dust is also discarded from alkali bypass systems, installed to avoid excessive build-up of alkali, chloride and/or sulphur, however bypass dust, as opposed to CKD, consists of fully calcined kiln feed material.

15. In the EU, the BAT conclusion for process waste, in the cement manufacturing sector in general, is to re-use collected particulate matter in the process, wherever practicable, or to utilise these dusts in other commercial products, when possible. (EIPPCB, 2010).

16. To avoid disposal, most CKD and bypass dust is recycled directly back to the cement kiln or cement clinker grinder. In clinker manufacture, CKD partially offsets the need for raw materials such as limestone and natural rock constituents, thus avoiding the energy usage and emissions related to their extraction and processing. Periodically some dust may need to be removed from the system due to increasing concentrations of alkali, chloride and sulphur compounds that may compromise the quality of the clinker. Dust that cannot be recycled back into the process is removed from the system and often collected onsite in piles.

17. Where appropriate CKD not returned to the production process may be recovered in various types of commercial applications, including agricultural soil enhancement, base stabilizing for pavements, wastewater treatment, waste remediation, low-strength backfill and municipal landfill cover (U.S. EPA, 2010). These applications depend primarily on the chemical and physical characteristics of the CKD.

18. The major factors determining CKD characteristics are the raw feed material, type of kiln operation, dust collection systems, and fuel type. Since the properties of CKD can be significantly affected by the design, operation, and materials used in a cement kiln, the chemical and physical characteristics of CKD must be evaluated on an individual plant basis. (U.S. EPA, 2010) Until the degree of variability in the CKD has been established, frequent testing is recommended.

19. Depending upon the level of contaminants of concern (for example, heavy metals, POPs), this waste can in some cases be hazardous waste for which special handling and disposal measures apply (UNEP, 2007). A study by Karstensen (2006b) reports an average concentration of 6.7 ng I-TEQ/kg for PCDDs/PCDFs in CKD and a maximum concentration of 96 ng I-TEQ/kg. The same study shows that wastes from the cement industry have PCDD/PCDF levels in the same magnitude as foods such as fish, butter, breast milk, and less than the maximum permissible concentration of 100 ng TEQ/kg for sewage sludge applied to agricultural land.

20. To ensure the protection of public health and the environment and to prevent groundwater contamination, bypass dust or CKD, discarded from facilities that use hazardous wastes as supplementary fuels or raw materials, should be analyzed for metal and organic leachate quality parameters if they are to be disposed of on land. The analysis should be conducted during controlled test runs in addition to ongoing testing that may be required by local regulatory authorities. Releases of dust to the air should also be controlled.

Emissions to water

21. In general, wastewater discharges are usually limited to surface run-off and cooling water only and cause no substantial contribution to water pollution (EIPPCB, 2010). Nevertheless, in the European Union the use of wet scrubbers is a BAT to reduce the emissions of SOx from the flue-gases of kiln firing and/or preheating/precalcining processes (EIPPCB, 2010). As such, the generation and management of wastewater shall subject to the requirements under Environmental Quality (Effluent) Regulations 2009, so as to limit the transfer of pollutants from the air into water.

End-product control

22. Final products such as clinker and cement are subject to regular control procedures required by the usual quality specifications as laid down in applicable national or international quality standards.

23. As a principle, co-processing should not alter the quality of the cement being produced. This means that the clinker, cement or concrete produced should not be used as a sink for heavy metals. There should be no negative impact on the environment as might be demonstrated with leaching tests on concrete or mortar, for example. The quality of cement should also allow end-of-life recovery.

24. Organic pollutants in the materials fed to the high temperature zone of the kiln system are completely destroyed, while the inorganic components are incorporated into the end product. Accordingly, the use of wastes in the clinker burning process may change the metal concentrations in cement products, and depending on the total input via the raw materials and fuels, the concentration of individual elements in the product may increase or decrease as a result of waste co-processing (EIPPCB, 2010). However, lengthy investigations have shown that the effect of waste on the heavy metals content of clinker is marginal on a statistical basis, the one exception being the bulk use of tires which will raise zinc levels (GTZ, 2006).

25. As cement is blended with aggregates to form concrete or mortar, it is the behaviour of the metals within these building materials that is important for the evaluation of relevant environmental impacts of waste used in the production process. Studies have shown that metal emissions from concrete and mortar are low, and comprehensive tests have confirmed that metals are firmly incorporated in the cement brick matrix. In addition, dry-packed concrete offers high diffusion resistance, which further counteracts the release of metals. Tests on concrete and mortar have shown that the metal concentrations in the eluates are noticeably below those prescribed, for instance, by national legislation. Moreover, storage under different and partly extreme conditions has not led to any environmentally relevant releases, which also holds true when the sample material is crushed prior to the leaching tests. (EIPPCB, 2010).

26. In regard to the above, the main results of leaching studies done to assess the environmental impacts of heavy metals embedded in concrete are as follows (GTZ, 2006):

(a) The leached amounts of all trace elements from monolithic concrete (service life and recycling) are below or close to the detection limits of the most sensitive analytical methods;

(b) No significant differences in leaching behaviour of trace elements have been observed between different types of cements produced with or without alternative fuels and raw materials;

(c) The leaching behaviour of concrete made with different cement types is similar;

(d) Leached concentrations of some elements such as chromium, aluminium and barium may, under certain test conditions, come close to limits given in drinking water standards; hexavalent chromium in cement is water-soluble and may be leached from concrete at a level higher than other metals, so chromium inputs to cement and concrete should be as limited as possible;

(e) Laboratory tests and field studies have demonstrated that applicable limit values, for example, groundwater or drinking water specifications, are not exceeded as long as the concrete structure remains intact. For example, in primary or service life applications;

(f) Certain metals such as arsenic, chromium, vanadium, antimony, or molybdenum may have a more mobile leaching behaviour, especially when the mortar or concrete structure is crushed or comminuted (for example, in recycling stages such as use as aggregates in road foundations, or in end-of-life scenarios such as landfilling);

(g) As there are no simple and consistent relations between the leached amounts of trace elements and their total concentrations in concrete or in cement, the trace element content of cements cannot be used as environmental criteria.

27. Assessments of the environmental quality of cement and concrete are typically based on the leaching characteristics of heavy metals to water and soil. Various exposure scenarios need to be considered (GTZ, 2006):

(a) Exposure of concrete structures in direct contact with groundwater ('primary' applications);

(b) Exposure of mortar or concrete to drinking water in distribution (concrete pipes) or storage systems (concrete tanks) ('service life' applications);

(c) Reuse of demolished and recycled concrete debris in new aggregates, road constructions, dam fillings etc. ('secondary' or 'recycling' applications);

(d) Dumping of demolished concrete debris in landfills ('end-of-life' applications).

28. Careful selection and monitoring of the waste ensure that the use of wastes does not result in metal emissions of any environmentally harmful magnitude (EIPPCB, 2010). However, in cases where the concentration of heavy metals exceeds the normal range found in cements made without alternative fuels and/or materials, leaching tests on mortar and/or concrete should be conducted (GTZ, 2006).

29. For “real-life” concrete and mortar exposure scenarios, different leaching tests and assessment procedures should be applied. Although standardized test procedures exist for waste management regulations and drinking water standards, there remains a need for harmonized and standardized compliance test procedures based on the exposure scenarios outlined above. It is recommended that a certified independent testing laboratory perform these at least annually.

MONITORING

30. Emission monitoring should be conducted to allow authorities to check compliance with the conditions in operating permits and regulations, and to help operators manage and control the process, thus preventing emissions from being released into the atmosphere. It is the responsibility of the competent authority to establish and set appropriate quality requirements, and to consider a range of safeguards. For the purpose of compliance assessment use of the following is considered good practice (EIPPCB, 2003):

(a) Standard methods of measurement;
(b) Certified instruments;
(c) Certification of personnel;
(d) Accredited laboratories.

31. For self-monitoring activities the use of recognised quality management systems and periodic check by an external accredited laboratory instead of formal own accreditation can be appropriate (EIPPCB, 2003).

32. More useful information regarding monitoring principles can be found in the European Commission’s Reference Document on the General Principles of Monitoring (EIPPCB, 2003).

<u>Process monitoring</u>

33. To control kiln processes, continuous measurements are recommended for the following parameters (UNEP, 2007; EIPPCB, 2010):

(a) Pressure;
(b) Temperature;
(c) O2;
(d) NOx;
(e) CO;

(f) SO_2 , when the SOx concentration is high (it is a developing technique to optimise CO with NOx and SO_2).

34. In the EU, the BAT conclusion for the cement manufacturing sector as a whole is to carry out monitoring and measurements of process parameters and emissions on a regular basis, such as (EIPPCB, 2010):

(a) Continuous measurements of process parameters demonstrating process stability, such as temperature, O2, pressure, exhaust gas flow rate, and of NH3 emissions when using selective non-catalytic reduction (SNCR);
(b) Monitoring and stabilising critical process parameters, for example, homogenous raw material mix and fuel feed, regular dosage and excess O_2.

Emissions monitoring

35. To accurately quantify the emissions, continuous measurements is BAT for the following parameters (UNEP, 2007):

(a) Exhaust gas flow rate;
(b) Moisture (humidity);
(c) Temperature;
(d) Dust (particulate matter);
(e) O2;
(f) NOx;
(g) SO_2;
(h) CO.

36. Continuous measurement of TOC is also recommended. The operator should assure proper calibration, maintenance, and operation of the continuous emission monitoring systems (CEMS). A quality assurance programme should be established to evaluate and monitor CEMS performance on a continual basis.

37. Periodical monitoring at a minimum once per year is appropriate for the following substances:

(a) Metals (Hg, Cd, Tl, As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V) and their compounds;
(b) HCl;
(c) HF;
(d) NH3;
(e) PCDDs/PCDFs.

38. The BAT according to EIPPCB (2010) is to carry out monitoring and measurements of process parameters and emissions on a regular basis, such as:

(a) Continuous measurements of dust, NOx, SOx and CO emissions;
(b) Periodic measurements of PCDDs/PCDFs and metals emissions;
(c) Continuous or periodic measurements of HCl, HF and TOC emissions.

39. It is also possible to measure and monitor NH_3 and Hg continuously, and to sample PCCDs/PCDFs and PCBs continuously for analysis from 1 to 30 days (EIPPCB, 2010).

40. Performance tests should be conducted to demonstrate compliance with the emission limits and performance specifications for continuous monitoring systems, when the kiln is operating under normal conditions.

41. Measurements of the following may be required under special operating conditions (UNEP, 2007; EIPPCB, 2010):

(a) Benzene, toluene and xylene (BTX);
(b) Polycyclic aromatic hydrocarbons (PAHs);
(c) Other organic pollutants (for example, chlorobenzenes, PCBs including coplanar congeners, chloronaphthalenes, etc).

42. In case of hazardous waste disposal in cement kilns for the purpose of destruction and irreversible transformation of the POPs content in waste, the DRE should be determined (UNEP, 2007) and it is referred to the Updated General Technical Guidelines for the Environmentally Sound Management of Wastes Consisting of, Containing or Contaminated with Persistent Organic Pollutants (POPs) (SBC, 2007).

Environmental monitoring

43. Justifiable concerns about the environmental impact from the plant may require the implementation of an ambient air-monitoring programme. This should assess levels of key pollutants identified as a priority for environmental control. The arrangements should include control and downwind locations, including the area of maximum ground level deposition from stack emissions. A meteorological station should be provided for the duration of the ambient sampling exercise in a location free from significant interference from buildings or other structures.

Reporting requirements

44. Reporting of monitoring results involves summarising and presenting results, related information and compliance findings in an effective way. Good practice is based on consideration of: the requirements and audiences for reports, responsibilities for producing reports, the categories of reports, scope of reports, good reporting practices, legal aspects of reporting and quality considerations (EIPPCB, 2003)

45. Monitoring reports can be classified as follows (EIPPCB, 2003):

(a) Local or basic reports, which are usually prepared by operators (for example, as part of their self-monitoring) and, where appropriate, should meet any permit requirements. These reports may concern, for example, an individual installation, an occurrence, which covers a short period and needs to be reported promptly, or local audiences;

(b) National or strategic reports, which will generally be prepared by the competent authorities. These are usually summary reports and they typically concern, for example, several installations, longer periods in order to show trends, or national audiences;

(c) Specialised reports, which are reports on relatively complex or novel techniques that are occasionally used to supplement more routine monitoring methods (for example, telemetry, neural networks, or deposition surveys).

46. Good practices in the reporting of monitoring information include (EIPPCB, 2003):

(a) Data collection, which involves the acquisition of basic measurements and facts. Considerations of the following items are good practice in data collection: schedules (stating how, when, by whom and to whom the data are to be reported, and what types of data are acceptable); use of standard forms for collecting data; data qualification details (used to record whether data values are based on measurements, calculations or estimations); uncertainties and limitations data (details of detection limits, numbers of samples available); operational context details (details of the prevailing process operations and/or environmental conditions).

(b) Data management, involving the organisation of data and its conversion into information. Considerations of the following items are good practice in data management: transfers and databases; data processing; software and statistics; and archiving.

(c) Presentation of results, which involves the delivery of information to users in a clear and usable form. Considerations of the following items are good practice in the presentation of monitoring results, depending on the type of report: scope of the report (type of situation, timing requirements, location); programme of presentations; trends and comparisons; statistical significance (details on exceedences or changes that are significant when compared with the uncertainties in measurements and process parameters); interim performance (interim reports); strategic results (details on levels of compliance for different policies, activities, technologies, etc.); non-technical summaries (for the public); and distribution of reports.

47. In order for monitoring reports to be used in decision making processes they should be readily available and accurate (to within stated uncertainties). Good practice in accessibility and quality of the reports can be achieved by considering the following items: quality objectives and checks; competence; contingency arrangements; sign-off systems; retention of data; and falsification of data. (EIPPCB, 2003).

REFERENCES

1. Technical Guidelines On The Environmentally Sound Co-processing Of Hazardous Wastes In Cement Kilns, UNEP, 11 November 2011.

2. Environmental Quality Act 1974 and all related Regulations, Orders and Rules under the Act.

3. Malaysia Standard document MS EN 197-1.

DRAFTING COMMITEE

GUIDELINES ON ENVIRONMENTALLY SOUND CO-PROCESSING AND USE OF SCHEDULED WASTES IN CEMENT INDUSTRY

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