CHAPTER 1 - INTRODUCTION

1.1 A BRIEF HISTORICAL EXCURSUS

Since the dawn of human existence, people have produced what could be described as waste. But the issue of managing these wastes did not appear until human culture evolved past the stage of nomadic hunter-gatherer into a settled agricultural-based existence. During these times, waste management was not a real cause for concern. The relatively small populations lived in vast areas, and there was no shortage of places to discard food-scraps and excrement. Food-scraps even provided a source of nourishment for livestock or were used as fertiliser to enrich the cultivated soil. Broken implements, pottery or other materials which were no longer useful were simply discarded on scrap piles in outlying areas without further thought.

Today, archaeologists are able to gather detailed information on the state of human cultural development and prosperity by excavating ancient dump sites. As human culture advanced, increasing population densities created a very real need to manage both the solid waste and excrement being generated. Evidence exists that the first culturally complex cities in Mesopotamia and Indus established means of disposing of excrement through underground sewage pipes and practised separate collection of solid waste. Even in the Bible, we find reference to a waste disposal site. In the time of King Solomon's successors Asa, Hisia and Josia, the waste from Jerusalem was brought to the Kidron Valley, where it was incinerated in open fires (Anonymous, First Book of Kings). The ashes from these fires were then brought to Bethel, or were scattered over the graves of the nearby Jerusalem cemetery (Anonymous, Second Book of Kings).

Even with all that had been achieved in some of these civilisations, waste management took a turn for the worst in the cities of medieval Europe. Excrement, food waste and other materials were merely cast into the streets to be dealt with by the rain, wind, sun and any unfortunate passerby. The situation became so serious that solutions had to be found. Examples of these, albeit simple solutions, began to appear during the latter half of the 13th century. There is evidence that streets constructed in Hamburg, Germany, were designed with inclines leading to a central gutter to allow the rains to wash away wastes more easily. During the 15th century, increasing population densities forced municipalities to introduce waste collection systems. In some areas, prisoners of war, slaves and criminals were often used to carry out these onerous tasks, whereas other municipalities hired people to do the job. These people were either paid directly by the authorities or special taxes were collected.

In 1473, there was a new twist in waste management. An enterprising commercial hauler actually paid the City of Amsterdam for the right to collect putrescible wastes from the City and then sold the material to farmers in the surrounding countryside as fertiliser (Erhard, 1964). Although this form of waste management soon caught on in

bigger cities, the eventual glut of material made it difficult to market the putrescibles to farmers, and municipalities were finally forced to pay for hauling of the waste. The commercial viability continued to decline until the 17th century, when individual towns began to takeover waste management operations themselves.

With the industrial revolution in the 19th century, came the generation of new types of waste materials in previously unheard of quantities. Although many of these new wastes were not biodegradable, they were considered a problem due to their noxious nature. In North America, the marketing of putrescible waste to farmers was a common and relatively successful practice, however to reduce the quantities of other waste materials requiring disposal, other potentially valuable materials were separated using a three level collection system. This involved installing three-bin collection systems in homes. One bin was used to collect only organic kitchen waste, such as food scraps, which was then used for food for livestock. In some instances, milkmen performed a double duty by collecting this waste as well as their normal delivery duties. In major cities like New York, Boston and Chicago, fat was collected and recycled in special facilities, some of which remained in operation into the early 1900's.

Another bin was used to collect potentially marketable materials such as textiles, footwear, glass, metals and wood. The remaining bin was used to store the ashes generated from fireplaces and stoves. This form of waste collection system was also in evidence in some parts of Europe in the latter part of the 19th century (de Fodor, 1911). However, most European cities managed their waste by transporting it out of the city and dumping the material in designated areas. Animals foraged in the piles for food and the less fortunate were allowed to pick through the waste for whatever was salvageable (see Figure 1.1). Despite the efforts of municipalities, waste management could not keep pace with the rapidly growing population and the resulting burgeoning quantities of waste. By the early 1900's, annual per capita waste generation rates were growing. For example, it was estimated that New York City's annual rate was 540 Kg/person, London's exceeded 300 Kg/person, whereas Budapest, Munich and Zurich all exceeded 230 Kg of waste/person/year (de Fodor, 1911).

1.2 THE DEVELOPMENT OF WASTE INCINERATION

Although the relationship between hygiene and human health was first recognised in England during the 19th century, it took the high profile efforts of physicians like Max von Pettenkofer, Louis Pasteur and Robert Koch to emphasise the fact that epidemics of disease, such as cholera and typhoid, were the result of bacteria spread by unsanitary conditions, and not acts of God. Based on this need to manage waste in a sanitary fashion and the growing need to quench industries' thirst for fuel, the first waste incinerators were developed in England.

Needless to say, the first attempts at the process were not very successful. In 1870, attempts were made to burn waste in a retrofitted coal-burning furnace in Paddington.

Figure 1.1 Women Sorting the Waste of Vienna at the end of the 19th Century

de Fodor, 1911

The incinerator was designed so that coal was burned on a grate to provide the major source of heat to initiate combustion of the waste on a separate grate located above the coal grate. Unfortunately, the wet nature of the waste and poor heat transfer in the system resulted in what could best be described as a smouldering effect. Only the persevering demands of physicians to "disinfect" waste kept this, and other small units operating against heavy public opposition.

But even in these early attempts, it was noted that high temperatures in the furnace not only reduced the odour of flue gases, but they also generated an ash which was suitable for reuse as a building material. The first fully functional municipal solid waste incinerator was constructed in Manchester, England in 1876. The unit design included an induced draft fan which helped to maintain higher burning temperatures on the hearth. The facility operated for 27 years and the generated ash was used as a building material.

The next major development was based on the need to further reduce the odours of the flue gases. In 1885, the incinerator in Egling was equipped with what was dubbed "a cremator." The "cremator" consisted of a coal-fired grate in which the flue gases from the waste furnace were passed before being released into the atmosphere. Soon after, the energy release from waste combustion came under the study of scientists like Lord Kelvin. It was found that 1 Kg of waste could generate 1.5 Kg of steam, which subsequently led to the design and construction of the world's first combined waste incinerator/electrical power generation facility, in the municipality of Shoreditch in London, in 1897.

Early waste incinerators were operated in a batch-wise mode. The units were usually fed by hand, as illustrated in Figure 1.2. Removing the slag and clinker was also done by hand, although proved to be a difficult task at times due to the extensive slagging on the grates. An example of this is illustrated in Figure 1.3. The Figure also illustrates the design of the facility. Note that the individual units were located in close proximity to one another, to facilitate better heat transfer and to help start-up new fuel beds after a unit was cleaned out.

Design efforts soon began to focus on mechanical feeding and cleaning of the incinerator grates. Sequential feeding and deslagging provided a more homogenous temperature profile and hence improved combustion (Figure 1.4). Even at this early stage, the basic principles of waste incineration were comparable with those of today. For example, it was not merely satisfactory to disinfect the waste, but it had to be done in a manner which prevented the emissions of malodorous flue gases. In addition, it was preferable to recover the energy released during the process and make use of the ash which remained. In 1910, 194 English towns made use of waste incinerators. The proliferation of the practice also led to further innovations, such as the practice of using the waste feed as a gas tight seal for the furnace, which is still used today (Figure 1.5).

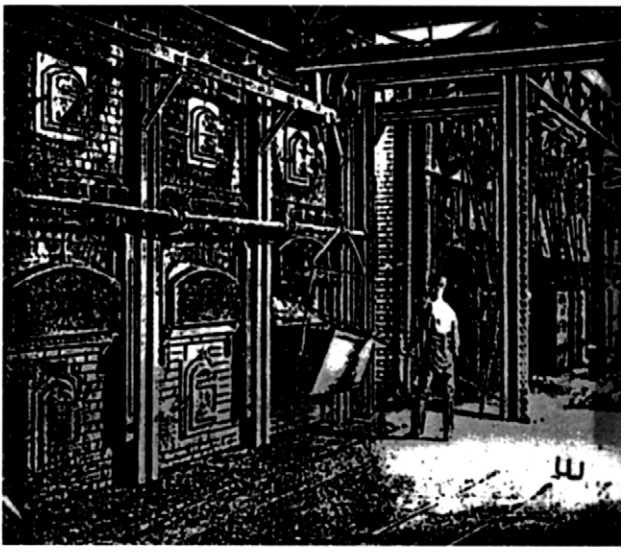
One of the most successful incinerator designs of the day was the Horsefall cell-type incinerator, developed by the Horsefall Destructor Company of Leeds. This was further modified by Heenan & Froude Ltd. of Worcester. These systems were generally operated as the final stage in a separation and reclamation system which was equipped with drum screens, magnetic separators and a hand sorting line. Figure 1.6 provides a cross-section schematic of this incinerator design. The refuse was charged onto the grate through an overhead hopper above the furnace chamber. The grates were stoked manually as the bottom ash was raked into a clinker channel below the grate. The only air pollution control device was a simple baffle system which kept the coarse particles and flaming paper from exiting the stack. Although these systems were operated without the benefit of a fan, surprisingly, some units were still in operation into the late 1960's (Tanner, 1967).

The development of waste incineration outside of the UK was slow to start, and was based mostly on the English technology. In 1892, the City of Hamburg decided to construct a municipal solid waste incinerator to cope with a growing waste management problem spurred by the reluctance of farmers to accept more waste, and more important, a major cholera epidemic. The facility went into operation in 1895 and had the capacity to burn a total of 16 tonnes of waste/day in two back-to-back units. Shortly thereafter, incinerators began to spring up all over Europe, especially in Germany, and major cities such as Brussels, Stockholm and Zurich (de Fodor, 1911). The latter facility was constructed at the Josephstrasse in 1904, and was a Horsefall design with 12 furnace cells and two boilers which generated 150 KW of electricity. It was replaced with a Heenan & Fourde design in 1928 which remained in regular use until 1969.

Figure 1.2 Manual Feeding of a Unit at the Glasgow Incinerator Facility

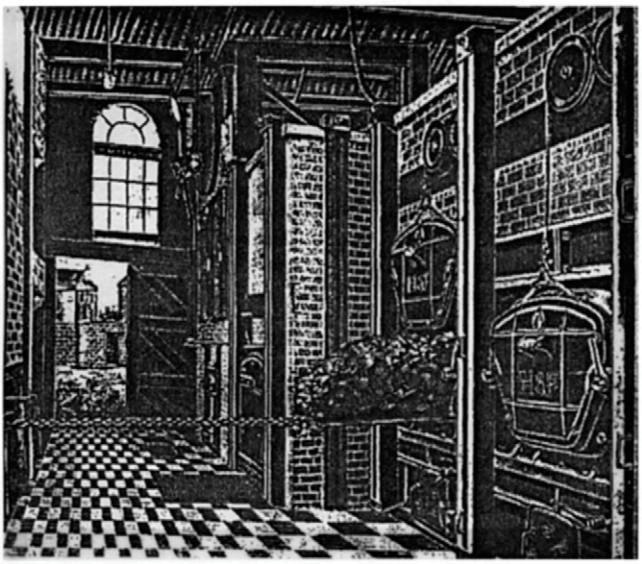
de Fodor, 1911

Figure 1.3 Manual Deslagging of the Fulham Incinerator



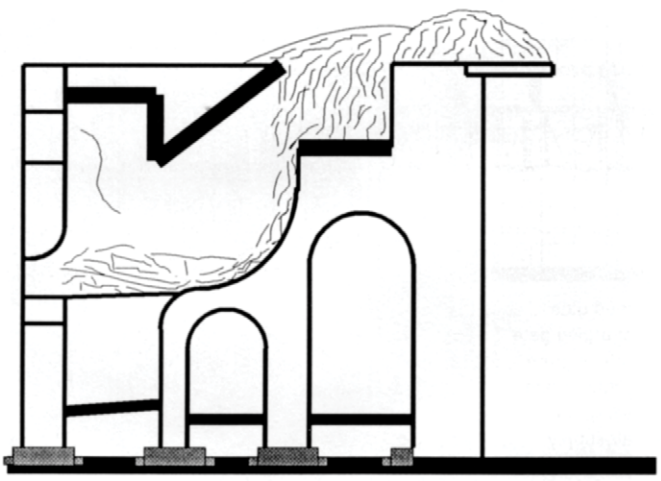
de Fodor, 1911

Figure 1.4 Mechanical Deslagging of an English Waste Incinerator Equipped with Trough Grates



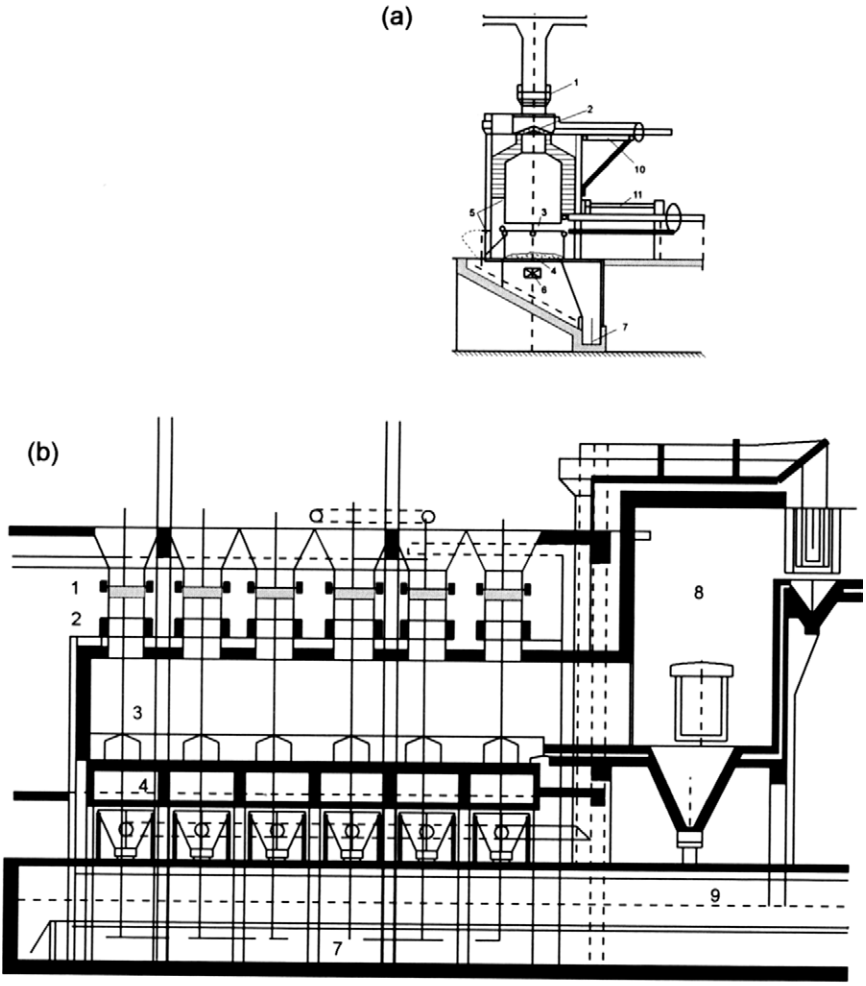
de Fodor, 1911

Figure 1.5 Cross-Section of a Grate System Using Waste as Gas Tight Seal



Adapted from de Fodor, 1911

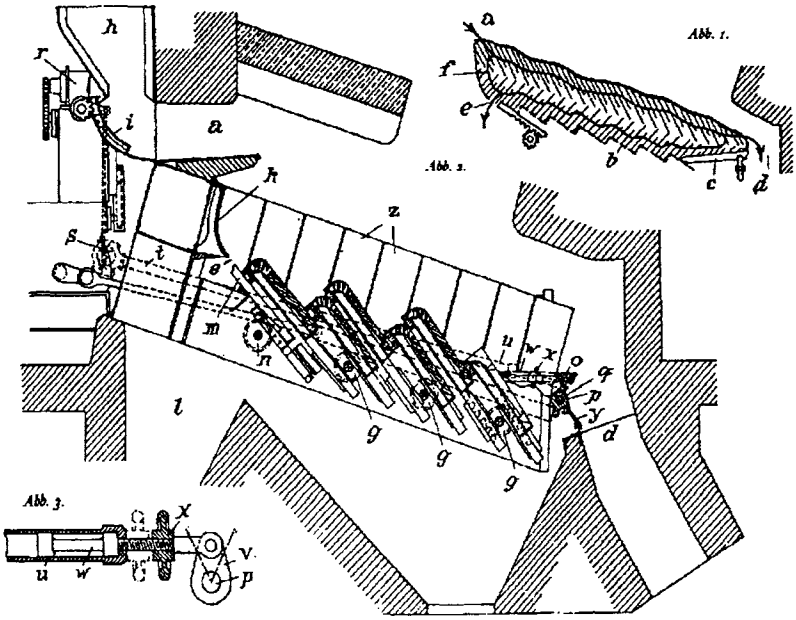
Figure 1.6 Sectional Diagram of One Single Horsefall Cell (a) and Longitudinal Section of Horsefall Cell Furnace (b)



Adapted from Tanner, 1967

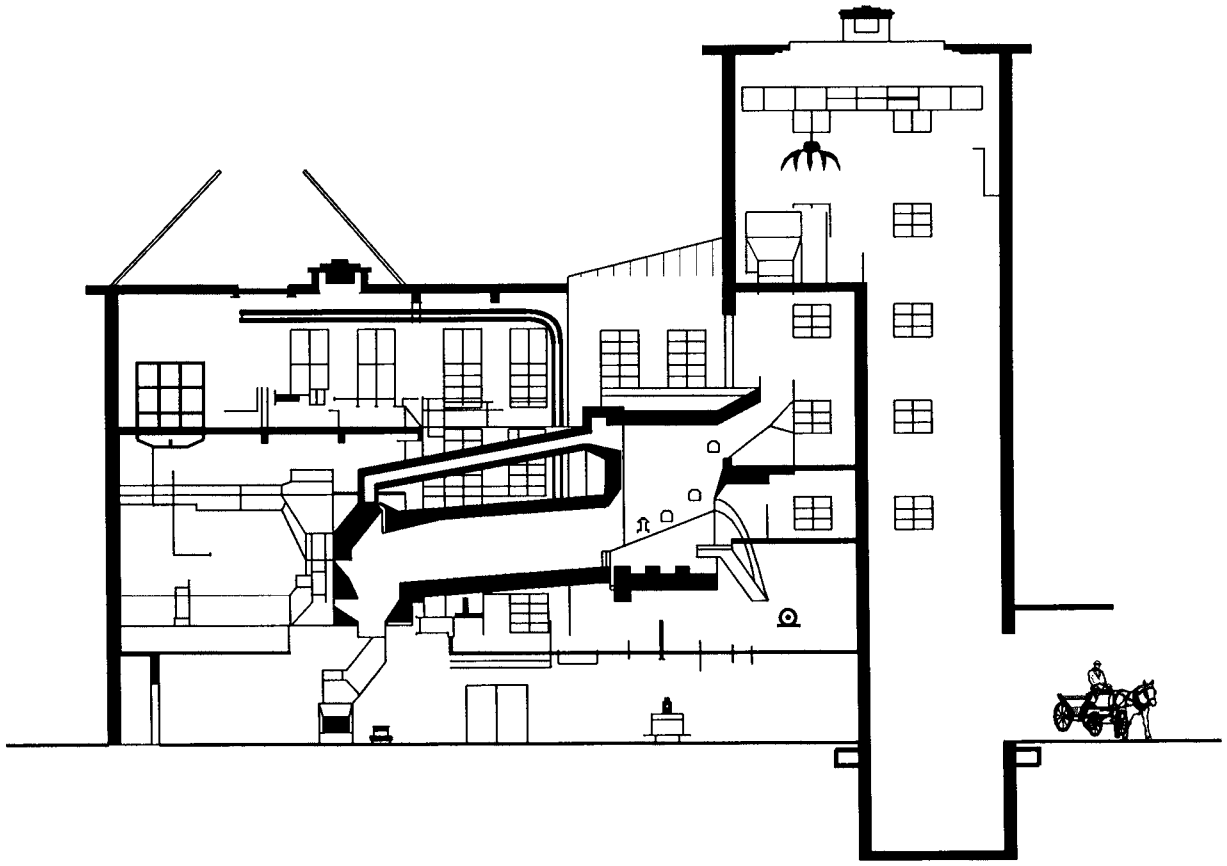
The early batch mode incinerators were based on a flat grate design, which resulted in relatively poor burnout of both the waste and the flue gases. Performance was greatly improved prior to the First World War by the development of mechanised inclined reciprocating grates which promoted steady-state combustion at elevated temperatures, which were facilitated by much better primary air distribution. An early design, still in use in modern incinerators, is the Martin reverse-acting grate shown in Figure 1.7, which was taken from the German patent 458540 of 1926. Its first application in waste combustion dates back to 1931. Another design which is still in use today is the system developed by Vølund of Copenhagen. It consists of a reciprocating primary grate, followed by a rotary kiln. The original design of the incinerator is shown in Figure 1.8, and albeit with some modifications over the years, was in operation until 1993.

Figure 1.7 Original Patent Drawing of the Martin Reverse-Acting Grate



Martin, 1926

Figure 1.8 Design of the Vølund Incinerator at Gentofte, Denmark (commissioned in 1932)



Adapted from Tanner, 1967

During the early 1900's, the practice of waste incineration was generally confined to urban areas. Alternatively, rural regions mainly practised composting and direct landfilling as a means of waste management. Especially during the two World Wars and the Great Depression, sorting and recycling were practised out of a need to conserve resources. Since the little waste that was generated was reused, the heating value of waste during these times was extremely low, and consequently there was little impetus to build new incinerator facilities. However, the economic boom of the post-Second World War era brought about many changes in lifestyles, including the stockpiling of prepared foodstuffs and an unprecedented increase in consumerism. Because these products were manufactured, shipped and stored in mass quantities, packaging was required to maintain the integrity of the products, and this packaging evolved slowly over the years. Glass and tin cans were soon replaced by paper and plastics. This, coupled with the fact that waste avoidance and recycling were not a major concern, eventually resulted in a huge increase in the heating value of municipal solid waste. Consequently, many new incinerators were constructed in the 1960's and 70's to deal with the increasing volumes of waste.

Most of these new incinerators were based on the designs of the 1920's. In 1957, Von Roll built the Borsigstrasse incinerator in Hamburg, and this design (Figure 1.9) provides a typical example of the type of incinerators built during the post-war era. Although the combustion efficiency and reliability of the operation were improved over the 1920's designs, there was little effort placed on reducing emissions to the atmosphere or improving the quality of the ash. The poor flue gas quality, especially the relationship to dioxin production, inevitably led to the vociferous public opposition against MSW incineration in the late 1970's and early 1980's. As a consequence, the installation of new incinerator facilities took a dramatic decline, exemplified by the temporary moratorium placed on the operation of facilities in Sweden in 1986.

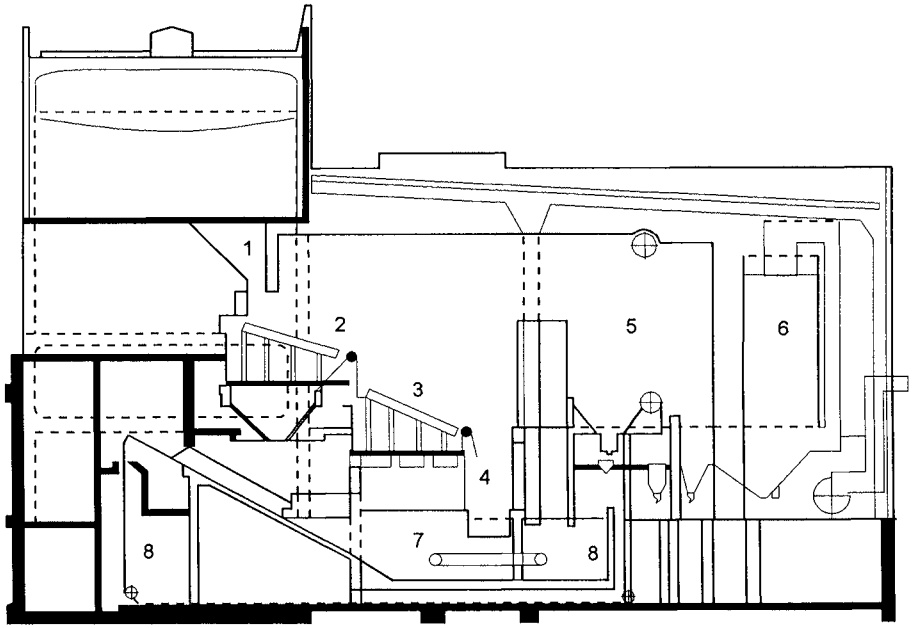
The incinerator industry was quick to react to the problems. As noted in Chapters 3 and 4, the designs of incinerators were changed to further enhance the operating conditions and reduce emissions of contaminants to the atmosphere. The most notable progress has been in the air pollution control technologies. This is illustrated by a comparison of emission values over the years (Table 1.1).

Table 1.1
Relative Improvements in the Reduction of Incinerator Emissions
(Mg/m^3 except PCDD/PCDF given in TE ng/m^3)

Time	APC Technology	Dust	HCl	SO_2	NO_x	CO	Hg	PCDD/ PCDF
1900	none	5,000	1,000	500	300	1,000	0.5	N/A
<1970	cyclones	500	1,000	500	300	1,000	0.5	N/A
1970-80	ESP's	100	1,000	500	300	500	0.5	N/A
1980-90	ESP + APC	50	100	200	300	100	0.2	10
>1990	latest APC	<10	<10	<50	<100	<10	<0.05	<0.1

N/A = not available
Adapted from Vogg, 1988

Figure 1.9 Design of the Von Roll Borsigstrasse Incinerator at Hamburg (1957)



1 = charging shaft
2 = drying grates
3 = main grate
4 = clinker generator
5 = boiler
6 = electric filter
7 = generator chain
8 = clinker chain

Adapted from Tanner, 1967

The improvements in the quality of atmospheric emissions over the past ten years are evident. The various methods available for flue gas cleaning have become well established, and the selection of equipment can be based on the individual needs to meet certain emission limits. The improvement in air emission quality has been so dramatic that the World Health Organisation no longer considers the emissions from modern, well operated and maintained MSW incinerators to be a hazard to human health or the environment (Suess, 1989). This has resulted in a shift of concerns from air emissions to the management of incinerator residues.

1.3 OBJECTIVE OF THIS TREATISE

In many countries, the potential impacts of these residues on the environment have come under close scrutiny and more stringent regulation. However, many of the concerns regarding the disposal of MSW incinerator residues have become controversial in nature, mostly due to inconsistencies based on:

- the different quantities and qualities of incinerator residue streams due to the type of incinerator and APC systems
- the heterogenous nature of the residue streams
- the lack of standardised sampling and analytical protocols
- the difficult process of comparing data from different studies
- the different conclusions drawn from different evaluation protocols
- the variations in regulations for residue management between different countries

Furthermore, the situation has become confused due to the broad scope of the technical information required to understand the characteristics of the residues, the fragmented data base and the uncertainty over the long-term behaviour of the residues in the environment.

Recognising there was a need to compile and evaluate the available information, the International Ash Working Group (IAWG) was established to conduct an in-depth review of the existing scientific data and develop a state-of-knowledge treatise on MSW incinerator residue characterisation, disposal, treatment and utilisation.

The project was designed to:

1) Define uniform protocols for the sampling and full characterisation of MSW incinerator residues, including chemical, physical and leaching properties;

2) Describe the fate and behaviour of contaminants during the incineration process, including documenting the effects of different incinerator designs, air pollution control systems, incinerator operations and refuse feedstocks;

3) Evaluate and develop recommendations with regard to the current or proposed disposal, treatment, utilisation and recovery practices;

4) Identify areas for further research and development.

The following chapters have been prepared to provide a detailed review of the existing information related to MSW incinerator residues. It is hoped that this information will place the issue of incinerator residue characteristics into perspective, and ultimately provide a framework for making sound decisions regarding their management in an environmentally acceptable manner.

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