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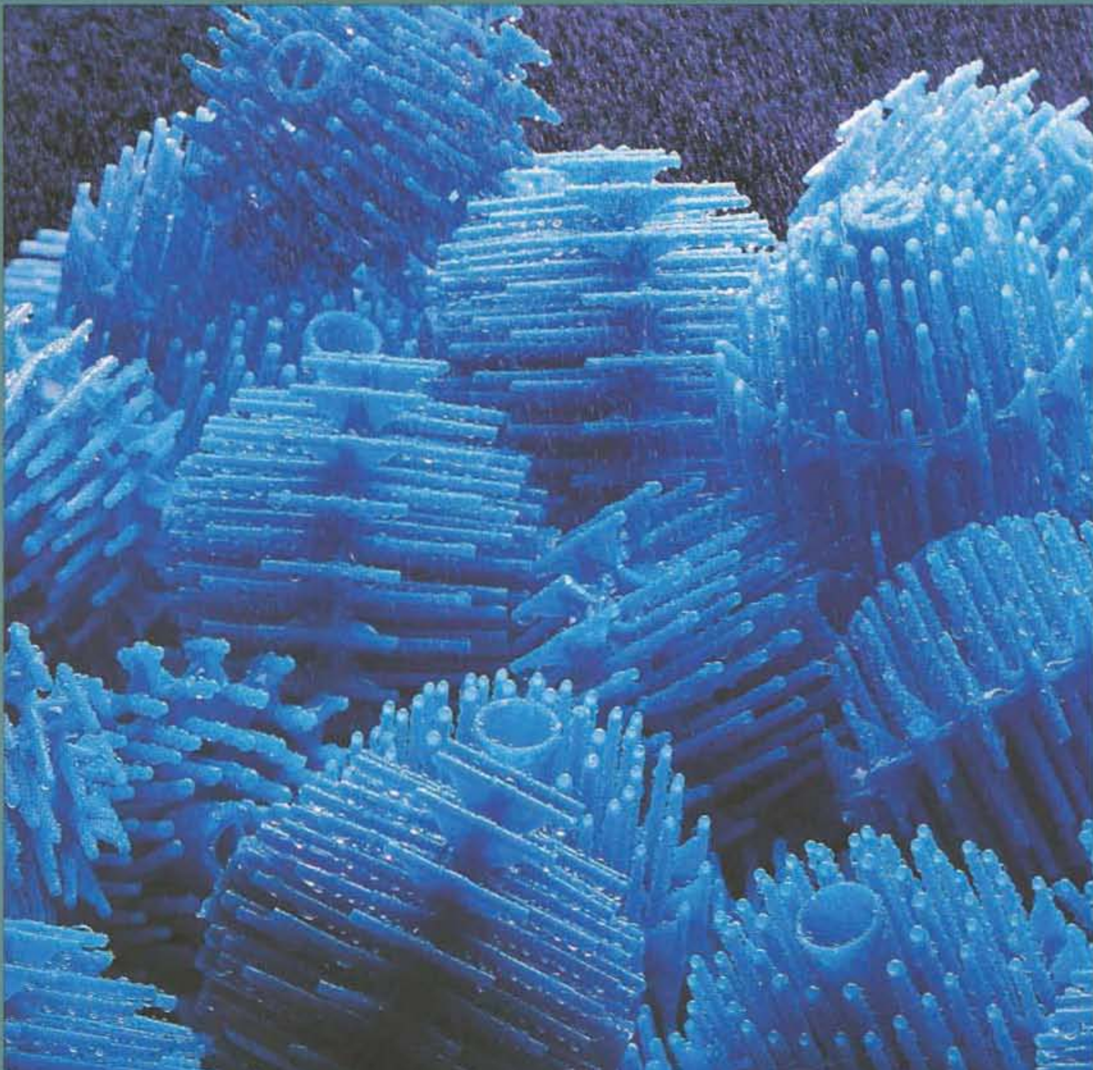

Municipal Waste Treatment Plants

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Vincent Di Chirico

Contents

Preface

Litter, garbage, refuse. All these terms conjure up visions of unsightly heaps of obnoxious, foul-smelling waste. Out of sight is out of mind, and our consciences are soon appeased once the rubbish, an unavoidable by-product of modern civilisation, is carted off elsewhere.

Industry and commerce generate vast quantities of waste. The more highly developed a society is, the more rubbish it produces. The higher the population density, the greater the environmental burden. In areas where there are only limited facilities for natural waste disposal, the willingness, the need and even the obligation to dispose of waste in a sensible and environmentally sound way is becoming more and more pressing.

Political, social and industrial leaders all acknowledge that the problem exists, and are now willing to take up the challenge. The solution must be effective and economical, but environmentally friendly as well. The tradition of eliminating, destroying and breaking down waste through incineration goes back many thousands of years, but the development and refinement of the required technologies has only really advanced over the last few decades, attempting to provide a solution to the problem of clean and practical disposal of hazardous waste produced by modern civilisation.

However, there are increasing calls for more environmentally sound installations that also satisfy aesthetic and cost/benefit requirements. Environmental technology companies are therefore under constant pressure to develop innovative and high-performance processes.

This is where the challenge to insurers begins. They must not only be in a position to offer clients insurance cover to protect them from the financial consequences of losses, but they must also have sufficient experience and know-how to play an active role in loss prevention.

This publication gives a broad picture of the many different facets of waste treatment. After introducing the various aspects of waste management in industrialised nations, the author provides a clear and detailed description of the most common technologies currently used. He draws on his extensive industrial experience to highlight the potential dangers inherent in the construction and operation of municipal waste treatment plants. This presentation is rounded off with observations on the insurance of technical risks and some practical underwriting advice.

By tackling this extremely topical subject, we hope to improve the understanding of the way municipal waste treatment (MWT) plants operate, and suggest ways of reducing or even avoiding loss exposure.

Richard Glückler
Engineering Department

Environmental pollution is one of the worst side-effects of the rapid economic growth seen in this century.

Foreword

Since the dawn of industrialisation our social conditions have consistently improved to the point where our material living standards are now at unprecedented levels as we approach the end of the twentieth century. On the down side, one of the worst consequences of this progress has undoubtedly been the spread of pollution, whose impact has led to a disturbing deterioration in our overall quality of life.

In the past, the interests of industrialisation and economic growth were in direct conflict with the preservation of nature. Our consumer society, with its enormous energy demands, has finally realised, however, that our natural resources are neither inexhaustible nor durable. As it continues to expand, industry is gradually paying more attention to the environment, both as regards more efficient use of energy and the control of hazardous emissions.

Although a return to nature is obviously out of the question, changing our behaviour is certainly an important step towards preserving the environment. Environmental protection has become an essential component in the management of modern society. It is a basic principle which we must respect in our behaviour and life styles. However, the path we have to travel to achieve a balance between sustainable economic growth and the conservation of the environment is long and tortuous. Green policies should not be synonymous with a slowdown in economic growth and industrial activity, but rather encourage a search for more efficient use of existing finite energy resources and raw materials.

However, avoiding pollution and hoping that waste production will be regulated merely by virtue of individual awareness and through everyday enforcement of basic rules is not enough to preserve our environment for future generations. Most of the problems connected with environmental protection can only be solved with the help of modern, high-performance technologies that also need to be economically viable.

In the past, waste treatment plants were suspected of being a major source of pollution – quite justifiably, in some cases. Since the introduction of stricter environmental controls, the design of these plants has advanced enormously, however, and they have now become a means of environmental protection, since they allow us to dispose of the mountains of waste we produce daily in an ecologically responsible way.

In the past the usual term was municipal waste incineration (MWI) plant, but nowadays it is more common to encounter names such as waste recycling centres (WRC), municipal waste treatment (MWT*) plants, or sometimes refuse to energy systems. These terms reflect the new ambitions of this technology within the context of integrated waste management programmes.

* MWT is the term used in this publication

The aim of this publication is to provide a global view of the problems associated with the management and thermal treatment of waste in industrialised countries. Our goal has been to provide an insight into the technologies available in municipal waste treatment without excessive technical detail. We have consciously avoided including scientific formulae or mathematical models, to make the content easier to digest.

This publication is divided into three sections. It describes the problems presented by the thermal treatment of waste in industrialised countries, from a technical, environmental and insurance viewpoint.

The first section provides an introduction to the history of waste disposal over the centuries: How has the production of waste and its characteristics evolved over time? We also look at the objectives of modern waste management and the new role played by MWT plants in our society.

The second section looks at the technical design aspects of the MWT plant. There is a brief description of tried and tested processes and technologies. Readers who want to find out more about the individual components that make up an MWT plant and how they function will also find useful information here.

The third section examines the insurance of engineering risks associated with the construction and operation of an MWT plant. The description of the various construction stages and the plant's commissioning, as well as the potential dangers during these periods, is intended to make underwriters more aware of this category of business in their risk analysis and premium rating approach.

We wish to thank all the companies kind enough to provide us with their specialised publications and photographic materials. In particular we wish to thank Von Roll Environmental Technology, Zurich, Widmer & Ernst Environmental Technology, Zurich, Deutsche Babcock in Krefeld, Germany and the Machinery Loss Prevention Service (MVD) of the Swiss Association of Technical Insurers (SVTV) for their contribution. We would also like to extend our sincere thanks to everyone whose hard work and input helped to bring this document into print.

Ancient Times

Archaeological excavations on the sites of ancient towns around the Mediterranean and in the Indus valley have shown that many towns had their own sewerage systems. In Crete, for example, ditches were dug to store solid waste and were emptied as required.

In Egypt and Greece human excrement was put in earthenware pots, presumably to be used as fertiliser on the fields, although there is no evidence to prove this. The Romans channelled clean drinking water over long distances to supply towns, and siphoned off waste water through drains leading into the "cloaca maxima", the main sewer that was laid along the bed of a river, into which the effluent was eventually discharged.

Although palaces and public buildings which already had toilet facilities were connected to the sewerage system, the same was not true of private houses: they had to collect their waste and excrement in earthenware pots which slaves would then empty into the drainage canals.

After the Roman Empire was overrun by the Germanic tribes, the sanitation systems gradually deteriorated. The drains were no longer cleaned out and clogged up. Effluent began to seep out into the streets, causing a terrible stench. One direct consequence of these conditions was the spread of the plague.

Power and powerlessness in the Middle Ages

In the Middle Ages, the great barons in their fortified castles disposed of food scraps and other refuse simply by throwing them over the castle walls. This is one reason why castle moats are such valuable archaeological sites. But just imagine the smell!

The situation in the towns was hardly any better: people simply dumped their rubbish on the streets.

A report on Paris in the eleventh century describes this sordid situation: filthy, pot-holed, unpaved streets, permanently covered in excrement and litter, no domestic sanitation systems, so that waste water simply collected in stagnant pools on the streets, adding to the general squalor.

One story illustrates just how bad things were: Philip II Augustus, king of France, was watching heavily laden vehicles pass in front of the palace window. The weight of the convoy stirred up the foul cocktail of excrement and rubbish on the streets, and the stench was so overpowering that the king fainted. He was so shocked that he ordered all the streets and squares around the palace to be metalled.

Although this is an example of the authorities – in this case the king of France – managing to successfully improve the hygiene standards of the time, it was very much the exception rather than the rule.

14th and 15th centuries

For the first time an edict issued by the Provost of Paris ordered all citizens to take their waste to sites specifically set aside for this purpose. The authorities stepped up their efforts, and saw to it that roads were metalled and paved in many towns. Despite constant threats of punishment, virtually nothing changed: city dwellers refused to dispose of their waste in the proper manner. The situation was the same right across Europe, from Paris to Nuremberg and Basle.

An even more squalid example:

- In 1840, Emperor Frederick III wanted to ride across the town of Tuttlingen, disregarding all warnings that the streets were virtually impassable. His horse had to pass down streets where the litter was so deep it reached its flanks.

Abb. 63. Pestarzt in einer Schutzkleidung. Kpfr. von Paulus Fürst nach J. Columbina 1656. München, Kupferstichkabinet.

During the vast plague epidemics that swept Europe, doctors wore a mask with a long nose shaped like a beak, filled with fragrant spices. Although a link was suspected between poor hygienic conditions and disease, there was still no understanding of how these diseases were transmitted.

- Three years later the Emperor had an even worse experience: as he entered the town of Rutlingen his horse fell, and both the rider and mount vanished under the mounds of rubbish!

Epidemics encouraged a temporary improvement

It was during the times of the plague that products such as eau de cologne first appeared. The popular belief was that rubbing it on the body could help to ward off the plague. Although people were right to suspect a close link between poor hygiene and disease, the mistake was in believing that the plague was caused by the terrible smell – just one of the many suppositions put forward to explain the origins of the epidemic.

Nevertheless, epidemics did tend to encourage new hygiene measures. Unfortunately these measures and decrees were only short-lived, and people quickly forgot the plague and the terrible loss of human life.

16th century

A "clean-up" was finally organised in Paris. A rubbish collection service, financed by taxes, was set up during the reign of Louis XII. François I subsequently introduced the use of baskets (predecessor to our modern dustbin) to collect litter rather than have people dump it on the streets awaiting collection by cart.

Despite this, these initiatives still did not have any long-term impact. People continued to empty their chamber pots straight into the streets, warning passers-by with a shout of "Mind your heads!"

During the same period waste disposal was proving to be more of a success in Holland. In Antwerp, for example, every citizen was obliged to clean his own section of the street and had to deposit his rubbish at the city gates. In Amsterdam special containers were provided for storing rubbish, which were then emptied outside the city walls.

18th and 19th centuries

Paris

Legislation was introduced right across France to make street cleaning compulsory. As a direct result, routes and timetables were drawn up for regular rubbish collections. In 1773 a police edict ordered all cesspools to be disinfected and deodorised with hydrochloric acid, and later on with chlorine.

In the 19th century the Count of Rambuteau designed the first cambered road to make it easier for water and litter to run off to the sides rather than accumulating in the middle of the street. He also ordered the construction of the first concrete sewers in Paris.

From 1853 onwards Haussmann, Prefect of the Seine, created a traffic system combining three networks:
• one for people
• one for traffic
• one for water supply and waste collection.

In 1883 Eugène Poubelle, who succeeded Haussmann as Prefect of the Seine, passed a decree making it compulsory for all property owners to supply their tenants with boxes for putting their rubbish in. Far ahead of his time, Poubelle introduced a system of waste separation: one box was reserved for putrescibles, another for paper and a third for glass.

Berlin

At the start of the seventeenth century the streets of Berlin were notorious as being the dirtiest in Continental Europe. Never cleaned at all, their main function seemed to be somewhere to keep pigs and household pets.

When the first regular street-cleaning services were introduced in Europe, convicted criminals or prostitutes were often requisitioned to do the work, which was considered to be degrading.

In 1677 the Great Elector issued a decree stipulating that all pigsties had to be located outside the city. It was not until the revolution of 1848 that there was any significant change in this sorry state of affairs.
From then on, the municipal authorities assumed responsibility for cleaning the streets, setting up an independent cleaning service.

Vienna

The city began a regular street cleaning service in 1782. To this end, prostitutes convicted at a cursory trial were requisitioned to sweep the streets. Their hair was shorn and they were given a broom to perform this arduous task under the supervision of guards.

It wasn't until 1864 that the municipal authorities assumed responsibility for organising and cleaning the streets. Around 500 staff were recruited to perform this service.

Berne

The city tackled the problem in the same way as Vienna. Here the prisoners were organised into street-cleaning teams. Six carts were pulled around the city by women, a squad of 22 swept the rubbish into piles while the other prisoners loaded it onto the cart.

Great Britain

Following an investigation ordered by the Royal Commission on hygiene conditions in a number of British towns, the government ordered city councils to construct sewerage systems to siphen off water and facilitate the removal of solid waste. This era saw the appearance of the first water closet (W.C.). Solid waste was stored in buckets and removed by the municipal waste collection service for subsequent dumping. Waste incineration started in Britain. The first plants capable of incinerating waste in a separate combustion chamber date from 1876.

Domestic refuse collection carts using transportable containers. Zurich's municipal cleansing department used these carts in the period 1910–1930.

Before the use of metal dustbins with lids became common practice, household rubbish was put out in all sorts of containers

20th century

Switzerland

By 1930 Switzerland had a daily refuse collection service. In very small villages rubbish was only collected when necessary. As a rule all the collected rubbish was dumped on waste ground not too far from the town. Organic waste decomposed into humus and this was normally used in farming.

Switzerland's first incineration plant was built by the city of Zurich and came into service on 10 May 1904. It is thought to be only the fourth plant of its type constructed on the Continent. Davos built an incineration plant in 1914.

The search for the ideal dustbin

Everywhere the search was on for a container capable of storing waste that was robust, resistant, and waterproof. It also had to have a tight-fitting lid, a simple design and be affordable.

It was J. Ochsner who came up with the solution, perfecting the design of the modern dustbin that carried his name in Switzerland. It had a sliding lid so that household refuse could be tipped in without generating too much dust. It was designed to fit the rubbish collection cart that he also invented in 1904. This system of refuse collection remained unchanged right up to the 1970s.

France

The French law of 15 July 1975 set down rules on waste disposal and established the "polluter pays" principle. Municipal authorities were given the responsibility of collecting and disposing of household waste. A year later, the law of 19 July 1976 placed waste treatment and disposal plants under the supervision of the government, with the aim of reducing the volume of rubbish, and organising its removal and recycling.

Waste treatment plants, along with the composting plants, incineration plants and municipal waste tips, are all treated as classified installations, i.e. they are subject to special regulations. As classified plants, they are governed by all the regulations and procedures set down in the articles of the law governing the creation, extension, operation, modification and discontinuation of all plant activities. One of the most recent laws passed in this area provides for the closure, between now and the year 2000, of dumps that accept untreated household waste.

Nowadays many local authorities in Switzerland have adopted the same system for financing municipal waste collection and disposal. Sorting household rubbish at source into recyclable materials such as paper and glass is encouraged by imposing a high tax on refuse sacks.

The history of waste incineration
The first furnaces

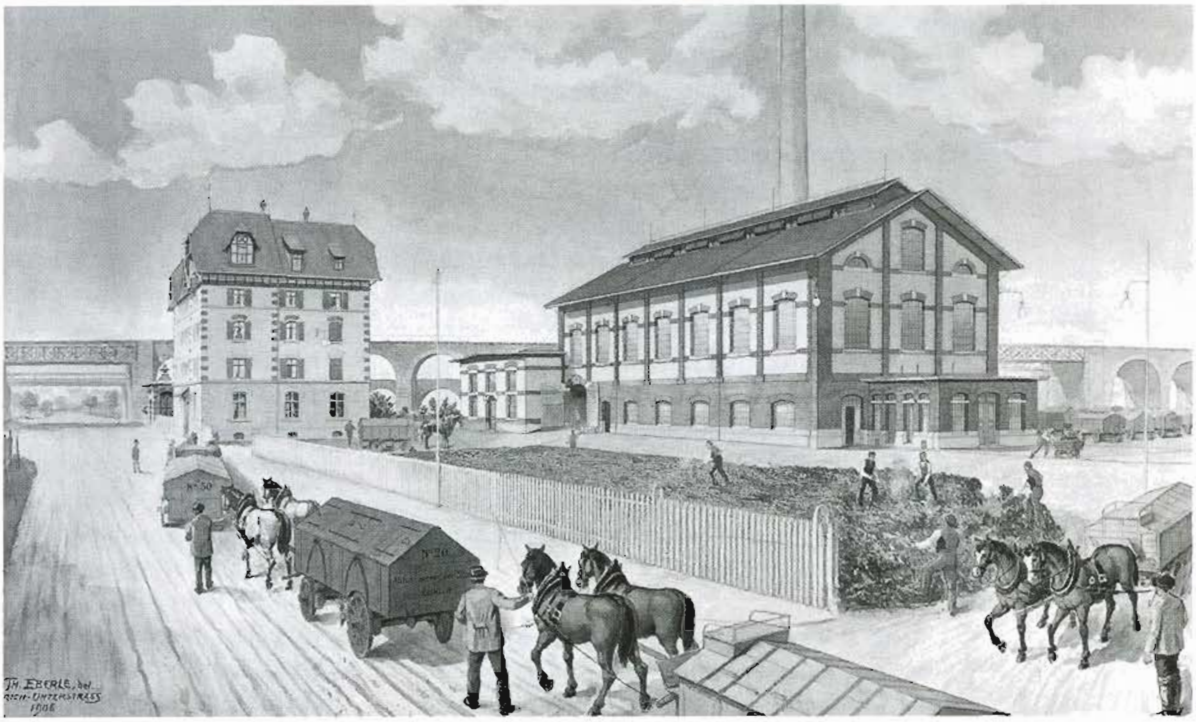
The first waste incineration furnaces started to appear towards the end of the 18th century. Not only was their design very basic, but they had many drawbacks both from a technical and environmental viewpoint. Until the 1920s both the loading of the furnaces and the removal of ash was performed manually, exposing furnace operators to flames, dust, fumes and soot-laden smoke.

The technology developed at the same pace as industrialisation, and these problems were gradually overcome by installing suitable machinery that handled most of the tasks performed by manual workers. The first mechanical combustion grates appeared in the 1920s. The pioneer in this field was the German, Joseph Martin, who patented a mechanical grate based on a counterflow system on 30 January 1926. From then on, the different processes involved were gradually mechanised and automated: loading the furnace, raking (or agitating) the waste, and removing the ash.

Although there has been a tendency to equate waste incineration furnaces with coal-fired furnaces commonly found in power stations, the design problems of the former are entirely different. Unlike coal, a combustible material whose properties can be termed "stable", the composition and the calorific value of waste is never constant, and continuously changes in tandem with the life-style of modern consumers. Because household waste has such a high inert content (up to the sixties, ashes from domestic wood and coal fires accounted for a substantial proportion of household waste), furnace designers spent a long time solving the problem of how best to achieve automatic combustion of waste with a very low calorific value. The design of the furnaces was simple as far as the technology was concerned, but complicated in terms of waste flow. Variations in the composition and calorific value of the waste quickly disrupted smooth operation. As a result, a plant that functioned perfectly well in one city would prove to be totally useless in another city.

The boilers were not at all reliable, since the waste in the furnace was agitated too vigorously, creating large amounts of dust, and the smoke was extracted too quickly, so that boiler linings quickly wore out due to the abrasive action. This problem, which still exists today, was exacerbated by the rapid corrosion of the boiler pipes because of substantial changes in the composition of waste since the end of the fifties. Plastic packaging and other composites, which make up an ever-increasing proportion of household rubbish, release their acids on combustion.

A waste incineration plant in Zurich's Josefstrasse in 1906. There was no waste storage pit – the waste was dumped in the open air. Many manual labourers were on the payroll at the time, but they were gradually made redundant as plants became increasingly mechanised.



Municipal waste treatment plant in Trimmis, Switzerland, which also produces electricity and hot water for district heating.

Recent developments

We can identify four main periods in the recent history of municipal waste incineration plants.

1st generation (1950–1965)

The main, and indeed the sole function of these plants was to incinerate waste. Heat recovery was only performed in very rare cases and treatment of gases was practically non-existent. As a rule, flue gases from the combustion process were simply passed through a water-cooled tower located above the combustion chamber and then discharged into the atmosphere. By way of example, the dust concentration of smoke emitted from the stacks of these older plants was approximately 1000 mg/Nm^3. In modern systems this figure has been reduced to 3 mg/Nm^3.

During this period the Swiss company Von Roll, who have since become world leaders in this field, constructed incineration plants in Lausanne (1959), Berne (1954) and Brussels (1957), some of which are still in service today.

2nd generation (1965–1975)

The main characteristics of this generation of technology are:

- an initial step towards environmental protection: the installation of new dust filters (cyclone or electrostatic precipitation) allowed atmospheric dust emissions to be substantially cut by reducing their concentration in the flue-gas to around 100 mg/Nm^3;
- growing interest in heat recovery. The first boilers installed during this period had to overcome many technical problems, such as abrasion, corrosion and fouling of heat exchange surfaces. Heat recovery from waste incineration, in the form of steam or hot water, was first thought to be an economically viable idea from 1890 onwards in the UK and the USA, but in 1980 most waste incineration plants in service had still not been fitted with heat recovery boilers;
- high-capacity installations were constructed and new furnace manufacturers appeared on the scene, including the German company Deutsche Babcock with its system of roller grates.

3rd generation (1975–1990)

The aim of this generation of technology was to improve the energy performance and above all the environmental standard of MWT plants:

- the general public started to become more aware of environmental problems and lobbied for the installation of flue-gas treatment systems designed to reduce acidic gas emissions. This led to the construction of the first flue-gas treatment plant capable not only of trapping dust but also of neutralising acids (hydrochloric acid, sulphur dioxide, hydrogen fluoride) and reducing the concentration of heavy metals in air emissions. Initiatives were also launched to reduce pollution in the area of solid waste and effluent from MWTs;
- the furnace/boiler system was substantially improved, thereby optimising energy performance and ensuring complete combustion of organic matter. A large number of technical operating problems were successfully solved. Almost the entire operation of the plant was centralised and automated;
- the incineration plants have now become waste treatment centres incorporating energy recovery based on a cogeneration procedure.

4th generation (1990–present)
Under pressure from the Green movement, waste treatment plants are now striving for zero pollution. Flue-gas treatment systems have to do more than simply reduce the dust and acid content of emissions, but must also be able to remove other pollutants such as nitrogen oxide, dioxins and furans. By installing sophisticated technologies and committing substantial investments, it is now possible to reduce the concentration of some pollutants in flue-gas emissions to almost undetectable levels.

These plants also incorporate advanced systems for treating the incineration residue. The ultimate purpose of these technologies is to obtain an inert residue that can be either recycled or disposed of without posing any long-term threat to the environment.

With tougher environmental legislation, waste incinerators have now evolved into integrated waste treatment plants based on sophisticated technology.


PALACE

3 Waste management in industrialised nations

3.1 Goals of modern waste management

In recent years, waste disposal has become a matter of concern for all groups of society because of the growing mountains of rubbish created by higher consumption and the resulting environmental pollution problems.

Industrialised and densely populated nations have finally acknowledged that there is serious conflict of interests between two of society's goals: on the one hand, to increase the production of consumer goods, and on the other to try to preserve the environment by disposing of waste in an environmentally sound manner.

The production of waste is an unavoidable by-product of human and industrial activity. We cannot prevent it. However, we must try to manage it in an acceptable manner, by limiting production as much as possible and by disposing of any "unavoidable" waste in a way that is kind to the environment.

Because of greater public awareness, reducing the burden we place on the environment has now become one of the prime objectives of industrialised nations.

Obviously the main purpose of a modern waste management plant is to reduce environmental pollution. To achieve this we would need to pursue the following strategies:

- reducing waste production at source, by trying to influence manufacturing processes and consumption habits;
- reducing pollutants created by the production of consumer goods and making sure they are less toxic;
- organising and limiting waste transport;
- setting up permanent structures for keeping the public informed;
- reducing volumes of end-waste by greater reutilisation (recycling any reusable materials and recovering the energy contained in waste);
- reducing pollution by adopting environmentally-friendly waste treatment;
- banning untreated discharge and authorising the dumping of end-waste only.

Production of rubbish is inevitable, but greater awareness at all levels of society would encourage a reduction in volume.

3.2 Integrated waste management

This concept is currently very popular with many local and municipal authorities. It involves avoiding waste, recycling it, treating it and finally storing it.

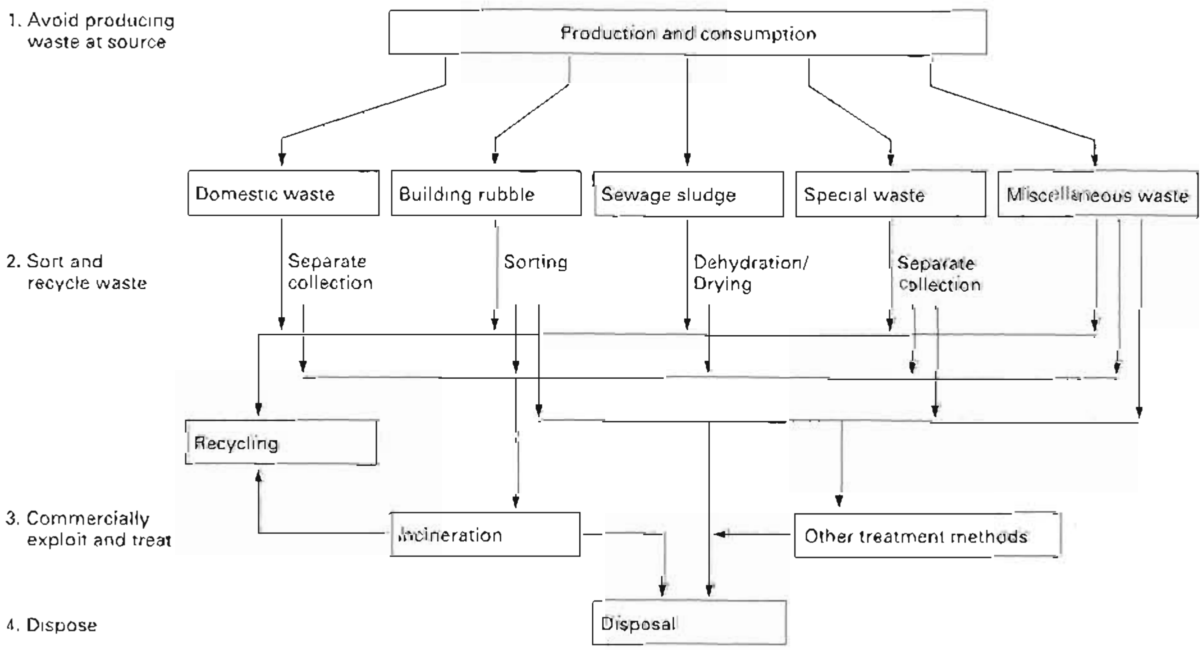
Obviously our top priority must be to avoid producing waste. The best way of avoiding waste is not to create any unnecessarily. A prime example of this is the cardboard packaging around tubes of toothpaste, which serves no purpose at all and which some distributors have done away with quite successfully. This measure has allowed several hundred tonnes of cardboard packaging to be saved every year without having any negative effect on the sales of the product in question.

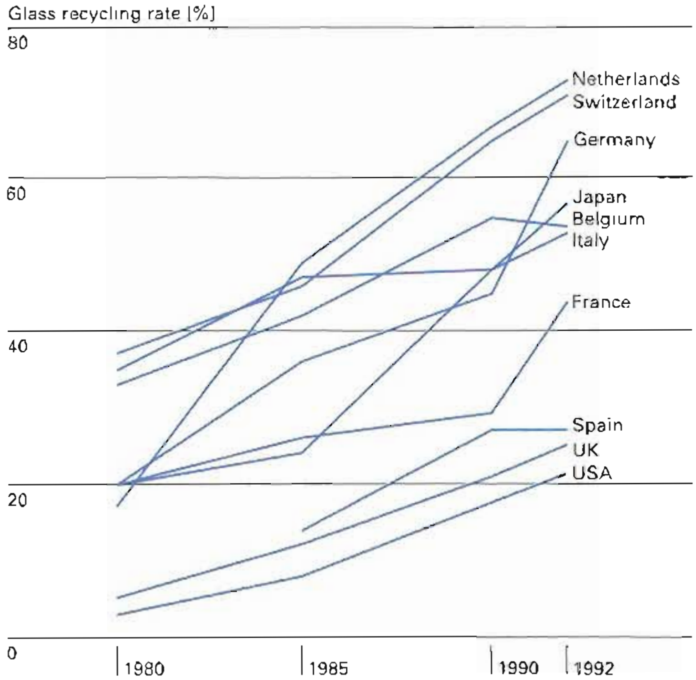
The second priority is to exploit the commercial value of waste by sorting and recycling it. Some countries have achieved a very high rate of recycling of glass and paper, for example. Laws and regulations governing waste management and treatment are increasingly requiring that the reusable components of household and similar waste (paper, glass, metal, organic waste, etc.) are collected separately and recycled.

Even so, the waste problem cannot be solved merely by reducing the amount of waste produced and stepping up recycling efforts. Furthermore, waste treatment plants and the storage of residues from them are still essential, even unavoidable to some extent. Waste disposal systems must transform waste into recyclable materials or inert residues, ensuring compliance with local and national environmental regulations. It must be possible to store these residues safely, for an unlimited period of time.

The non-recyclable part of household or similar waste, such as non-recyclable waste from building sites and sewage sludge of no commercial value, must be incinerated. The resulting residues must in turn be treated prior to subsequent disposal in secure landfills that do not present any threat to the environment. But controlled dumping, a complementary and indispensable technique, must be reserved for the end-storage of residual waste after recycling and treatment.

Basic principles of integrated waste management





Glass recycling rates (source: OECD Environmental Indicators).

By way of example, the French law governing waste disposal stipulates that as of 1 July 2002, landfill sites for waste disposal will only be authorised to accept end-waste. Under the terms of this law "end-waste" is material that may or may not be the result of waste treatment, and which is no longer capable of being treated according to current technical and environmental standards, in particular through the extraction of any part that is of commercial benefit or by reducing its pollutant or hazardous properties.

Comments on the sorting of household waste

Current standards for the sorting of raw domestic waste after it has been collected are rather poor. Materials that could be reclaimed or recycled are contaminated by organic matter. In future, sorting will therefore need to be performed at source, with a selective refuse collection system. In a number of countries this system has already proven to be an essential tool in strategies for global management of municipal waste.

There are three main options for waste collection and sorting: sorting at source (households sort their own rubbish by placing it in different bins), door-to-door collection (such as collection of waste paper in Switzerland) and householders taking recyclable materials to collection centres (bottle banks, used batteries, metals, etc.). Obviously none of these solutions are effective or sufficient individually: experiences in several countries show that only a combination of the three is effective in practice.

Sorting domestic rubbish after collection is not very effective. Recyclable waste has usually been contaminated by organic material

3.3 Waste production

From the 1960s onwards the standard of living in industrialised nations has markedly improved, to the point where we have become a true consumer society and enjoy affluent lifestyles. All sorts of goods are thrown away, because they are old or out-dated, even though they are still in perfect condition or could be repaired for a small sum.

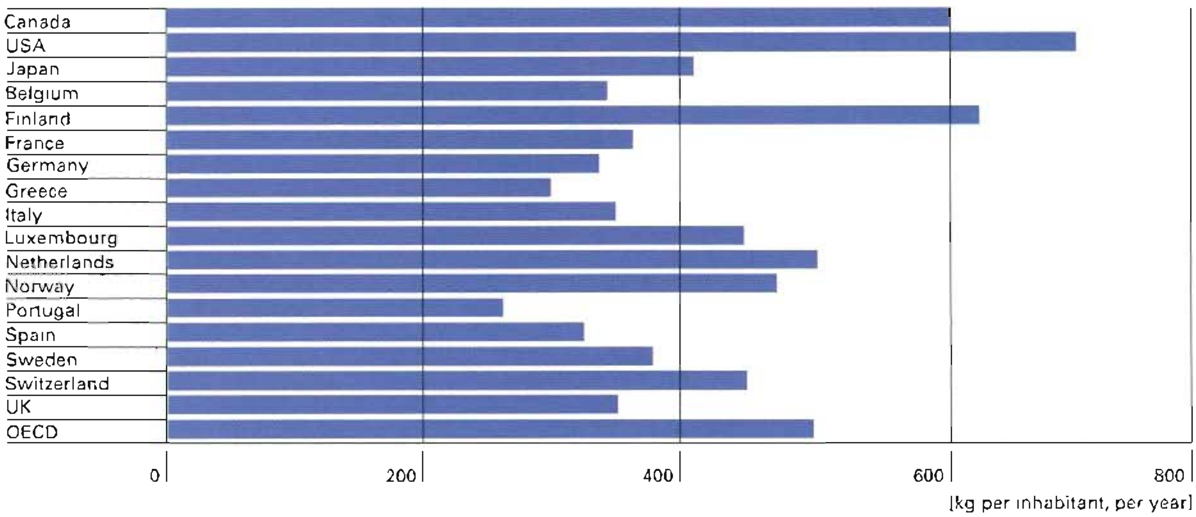
Studies have shown that the bigger the city, the higher the per capita figure for the production of household waste. Other factors such as the social environment, geographical location, living standards, etc. affect the production of household waste. The example of Germany illustrates how waste volumes are closely linked to levels of prosperity: in the former West Germany, average per capita waste production was as high as 380 kg/year, whilst in the former GDR it was 174 kg – not even half. At the moment the average figure for industrialised nations is 450kg of waste per person every year.

In France, according to statistics from the Department of the Environment, the quantity of waste collected and processed by the authorities is estimated at 580 million tonnes per year, equivalent to a per capita production of 10 tonnes/year.

This figure breaks down as follows: 30 m tonnes of household waste, 150 m tonnes of industrial waste and 400 m tonnes of generic or recycled waste produced by agriculture or agro-food industries. Of the household waste figure, around 700,000 tonnes is clinical waste. In addition to this, there are 2 million tonnes of what is classed as hazardous industrial waste which require special waste disposal methods.

These huge volumes of waste cannot simply be dumped in landfills. On the one hand, there are not many suitable sites, and on the other these mountains of waste pose a long-term threat to the environment. Pollution of groundwater and discharges of gases and leachate that have to be treated over several decades are just two examples of the problems faced.

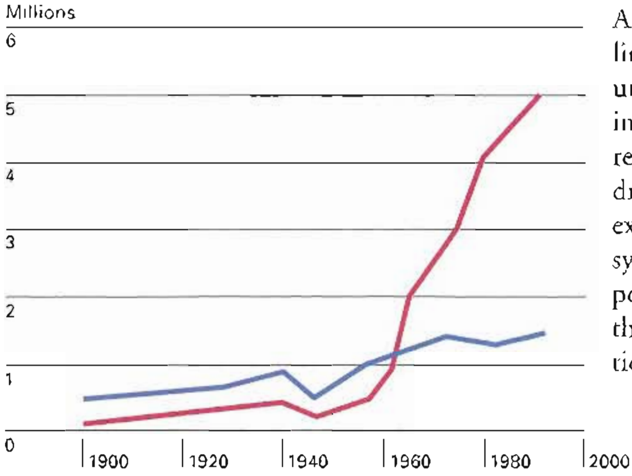
Average annual production of household waste per person in kgs (source: OECD Environmental Indicators).



Comparison of the growth in household waste produced by the population of Munich. Per capita waste production has doubled since 1970 and currently averages 415 kg per year. The volume of household rubbish has more than quintupled since 1960.

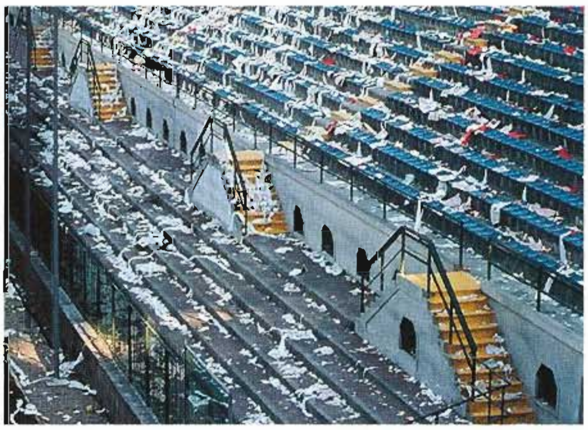
Annual household waste production (m^3)

Population



At the moment the waste problem is no longer limited solely to an increase in weight and volume. A new factor has come into play: a change in the composition of household waste. This is a reflection of our modern lifestyles, which have drastically changed over the last few years. For example, the prevalence of packaging made from synthetic or composite materials poses serious disposal problems: they are difficult to recycle and they release a number of toxic gases on incineration.

Glass bottles (with deposit paid) have been replaced by all sorts of containers, some of them suitable for recycling.



At sports events we leave behind mountains of rubbish, mainly in the form of packaging.

3.4 Nature and composition of waste

It is not easy to categorise waste, since even the definition of waste is problematic. Furthermore, each country has its own waste definitions and regulations. For example, EU legislation provides the following definition for waste: any material which someone disposes of, plans to dispose of, or is obliged to dispose of.

Waste is usually classed into three categories: domestic waste (also referred to as municipal waste), hazardous waste and industrial waste. In this document we have decided to use the following classification:

Harmless waste, including
- household waste (solid waste from private homes, waste of this type collected from hospitals, industry and workshops)
- waste from municipal cleansing departments (waste collected by street-cleaning services, municipal dustbins, dead leaves, etc.)
- discarded bulky objects (furniture, mattresses, household appliances, etc.)
- garden rubbish (leaves, branches, etc.)
- waste produced from forestry and farming (wood, manure, liquid manure, etc.)

Inert waste (materials that remain virtually unchanged over time, such as the rubble produced from civil engineering works)
- waste from demolition and building rubble
- residues from manufacturing processes, rendered inert by suitable treatment

Special waste (waste containing toxic products)
- sewage sludge (only in certain cases)
- waste from industry and workshops (solvents, paints, used oils, batteries, composite materials, expired medicines, etc.)

Miscellaneous waste (treated or recycled by special processes)
- old cars
- used tyres
- animal carcasses
- computer hardware
- televisions, refrigerators, etc.
- other waste collected separately (paper, glass, aluminium, fabric, etc.)

Radioactive waste (waste with low, medium or high radiation factor)

Main categories of waste

Municipal waste:	Other types of waste:
• Waste from: - private homes - hospitals* - industry and workshops	• Used tyres • Special waste • Radioactive waste
• Discarded bulky objects	• Sewage sludge
• Garden refuse	• Scrapped cars
• Waste from municipal cleansing departments	• Animal carcasses
	• Waste from industry and workshops
	• Waste produced from forestry and farming
	• Waste from demolition/ construction, and building rubble

*uncontaminated

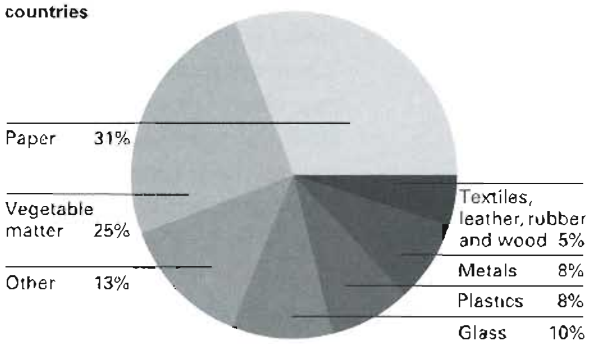
Main categories of waste

The table opposite shows gives an idea of the quantities of waste produced in Switzerland, broken down by category (estimate for 1987, in millions of tonnes) Source: OFPE

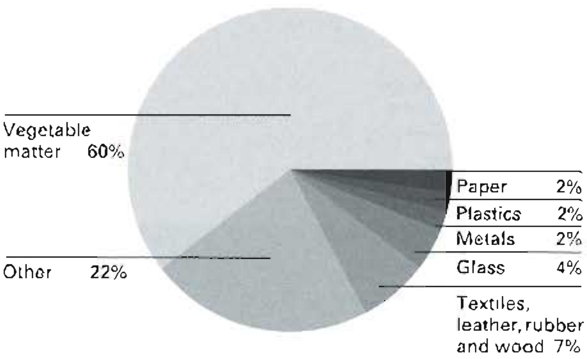
Municipal waste	2.8
Reusable waste originating from:	
Industry and workshops:	
scrap iron	0.7
old cars and	
metal waste	0.35
used aluminium	0.025
Households and small businesses:	
paper	0.5
glass	0.14
organic matter	0.05
fabric	0.015
aluminium	0.0005
Demolition waste (skips)	2.0
Waste from industry and workshops	1.0
Special waste	0.3
Sewage sludge	4.3
Carcasses	0.15
Miscellaneous	0.1
Total	12.5

Municipal waste comprises a complex mixture of objects and materials each with very different characteristics. These pie charts show the approximate distribution, in weight, of the various materials contained in municipal waste, which depends mainly on a society's living standard (Source: Environmental Resources Limited).

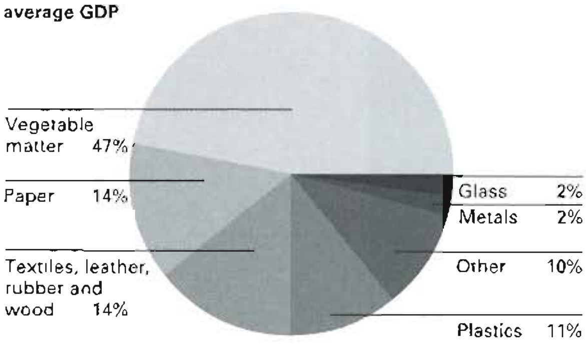
Major industrialised countries



Countries with low GDP



Countries with average GDP



The packaging problem

Packaging has played a significant role in the development of waste. Statistics show that over the last thirty years, the mass of used packaging discarded by households trebled, while in global terms domestic waste increased by 60% (measured by weight) over the same period.

Each year in France alone people throw away 80 billion packages, empty bottles, cartons, plastic containers, etc. Currently in excess of 6 million tonnes a year, packaging accounts for a third of household waste in France and over 50% measured by volume, causing a real headache for the authorities who have to dispose of it. The passing of regulations to make industrial producers responsible for their packaging and its eventual recovery should go some way towards solving this problem.

Annual packaging consumption per head of population:

USA	250 kg
France	180 kg
Burundi	4 kg

(Source: ATOCHEM, Packaging Conference 1990)

In industrialised countries, packaging is the biggest component of municipal waste

The sewage sludge problem

Source and quality of sewage sludge:
An EU directive governing the treatment of effluent specifies that over the next 10–15 years effluent from urban zones will have to be processed in sewage treatment plants and, in ecologically sensitive areas, any nitrogen and phosphorus removed. Sewage treatment plants have been constructed in many countries, but the type of treatment provided and the percentage of population served by these facilities still varies a lot from one country to the next.

Sewage treatment produces a sludge, whose quality and quantity varies according to the type of effluent treatment used, and of course the quality of the effluent being treated. Different water treatment processes may result in varying levels of purification, which also have an influence on the quantity and quality of the sludge generated.

The basic conventional effluent treatment processes include:

- simple primary clarification;
- physical/chemical clarification;
- biological treatment using suitable bacteria.

All these treatments produce sludge which rapidly starts to ferment unless treated. A distinction is therefore made regarding "fresh sludge". Fermentation is prevented by "stabilising" the sludge. There are three methods used to achieve this: anaerobic digestion, aerobic stabilisation and chemical stabilisation. The purpose of the first two methods is to remove some of the volatile substances, while the last process blocks fermentation by raising the pH.

All the sludges are extracted in liquid form. Since this sludge is a by-product of effluent treatment, there has to be an economical way of disposing of it.

There are a number of possibilities:
• controlled dumping;
• use in agriculture, either directly or after composting;
• incineration.

Controlled dumping is becoming less common, and furthermore landfill sites are being built in increasingly remote locations.

Sewage sludge is much more frequently used as a substitute for fertiliser in agriculture. The sludge has a high nutrient content (phosphorus and nitrogen) which can cause serious pollution of water courses and groundwater, a phenomenon known as eutrophication. In addition, sludge drawn off from treatment plants generally contains pollutants that have not been properly removed and which can have a harmful effect on the soil for many years. These pollutants mainly include heavy metals (zinc, copper, lead, cadmium, mercury, etc.), pathogens and parasites. As a result, the use of sewage sludge in agriculture has become a major problem for the environment, and several countries are now starting to limit or even ban its use in farming.

Incineration is now becoming the predominant method for disposing of sewage sludge, mainly because of the growing number of waste treatment plants fitted with the technology required to burn the sludge.

Whatever the final destination of the sludge, there is always a need to reduce its volume in order to cut transport costs and also in the case of incineration to obtain, where possible, sludges that spontaneously combust. Volume reduction is achieved by removing the interstitial water.

This operation is performed step by step, and it is always necessary to achieve the best possible yield from one stage before proceeding to the next one. Under these circumstances, investment and running costs can be reduced.

The first stages are the conventional ones:
• thickening the separated or mixed sludges by static or dynamic means;
• dehydration by mechanical means, which can take place after thickening, if fresh sludge is being treated, or after the sludge has been biologically stabilised by undergoing an aerobic or anaerobic process.

Thermal drying can be used to complement this process, resulting in sludges with a dry matter content of up to 90% or even greater.

The use of sewage sludge in farming is sometimes questioned because of the pollutants it may contain. Special technology is required to incinerate sewage sludge.

4 Technical design aspects of a municipal waste treatment (MWT) plant

4.1 How an MWT plant works

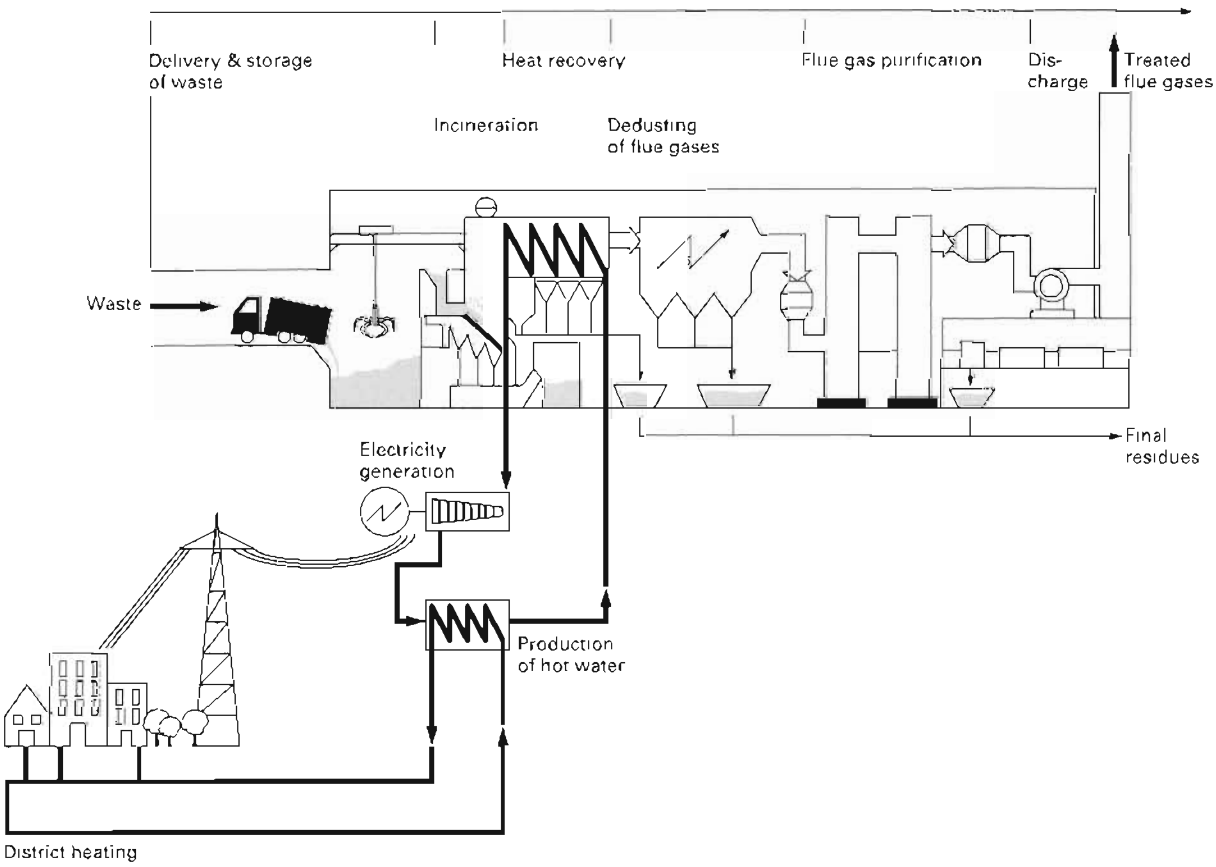
Trucks collect the municipal waste and dump their loads, after weighing, in the storage pit. The incineration furnace is constantly fed with waste by an overhead travelling crane equipped with a grapple. The combustion gases produced as the waste is incinerated on the grate of the furnace are forced around a boiler to produce steam.

This steam is normally used to generate electricity by means of a turbine. The electricity produced is used for the plant's own needs, and any surplus power is sold to the public grid. Alternatively – if the plant's location allows it, and if the infrastructure exists – the steam can be used to produce hot water for district heating or for industrial processes.

To start with, all the dust is removed from the combustion gases cooled in the boiler, and then the gases are purified in a very sophisticated flue-gas treatment system. Finally they are expelled into the atmosphere by an extractor fan that sucks them in and propels them up the stack.

The different residues produced by waste incineration and flue-gas treatment are collected separately and undergo suitable treatment before either being recycled or dumped.

Schematic diagram of an MWT plant



Scrubbing tower for the flue gases produced by waste incineration. Sophisticated technologies have to be implemented to ensure environmentally sound waste treatment

4.2 Thermal waste treatment

Incineration: an essential component of modern and environmentally sound waste management.

The practice of waste incineration began over a century ago in Britain, as an attempt to find a solution to the unbearable situation in big cities. Incineration was supposed to improve public health standards and prevent epidemics.

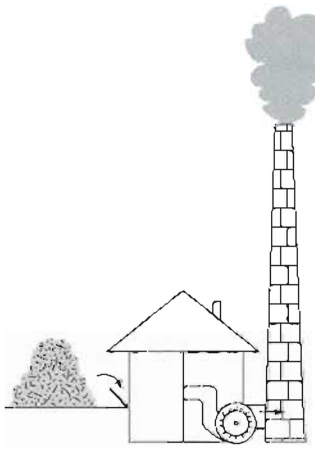
Like all technical installations, incineration plants have been continuously refined and improved over the years. However, from an environmental viewpoint, it has to be said that the first significant advances were not made until the mid-seventies, with the installation of the first flue-gas treatment systems. For over a century, engineers and designers concentrated all their efforts on improving the incineration furnace.

These plants consisted of nothing more than a furnace and a chimney stack, and were seen as truly heinous polluters by the local population.

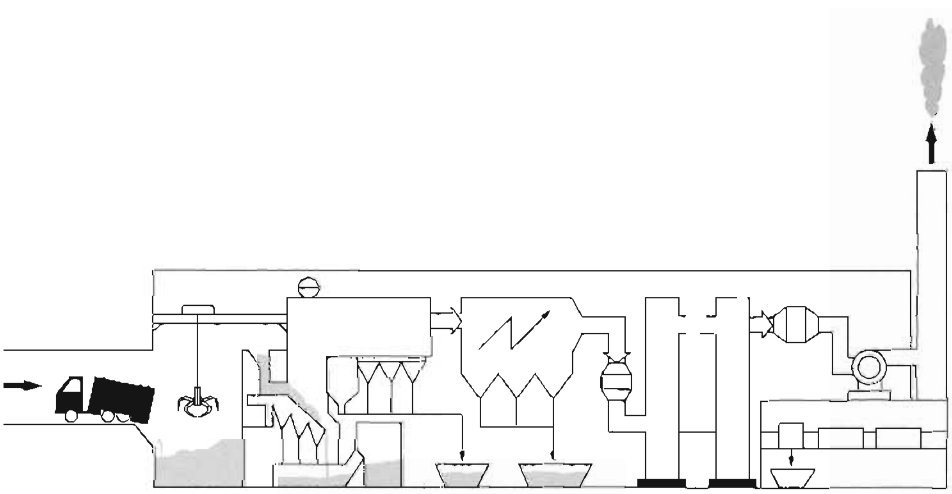
As public authorities and the general public have become more environmentally aware, it has prompted major advances in plant design. Nowadays waste incineration is an integral part of environmentally friendly waste management, and could even be considered to be the key element.

The latest generation of waste treatment plants meets the most stringent environmental protection requirements. The plants reduce pollutants – whether in solid, liquid or gas form (carbon monoxide, hydrochloric acid, sulphur dioxide, nitrogen oxides and hydrocarbons) – to quantities that are well below the maximum levels considered to be hazardous to human beings and the environment.

Until 1950, incineration plants only comprised a furnace and a chimney stack. Modern MWT plants have to perform far more complex tasks than simply reducing the volume and weight of waste through incineration.



Incineration plant in 1950



MWT plant in 1990

In order to meet the latest environmental controls, modern waste treatment plants must perform the following functions:

Reducing the volume and weight of waste

Since its inception, the purpose of waste incineration has been to reduce the quantity of end-waste.
Firstly, the volume is dramatically reduced: one cubic metre of household waste is converted into 0.1 cubic metre of solid residue after incineration. In terms of weight, 1000 kg of waste is converted into 300 kg of solid residue. The reduction in volume also means that less land is needed for public landfill sites.

Hygienic disposal

All the organic matter, plus any pathogens, are destroyed by combustion at temperatures in the region of 900°C. Thus, incineration also prevents microbial contamination, since bacteria and viruses are destroyed at temperatures above 200°C.

Energy recovery

Even if the incineration of household waste only contributes about 1% of the total energy of industrialised nations, it would be inconceivable nowadays to burn waste without recovering the energy at the same time.

Energy recovery can be applied in a number of ways:

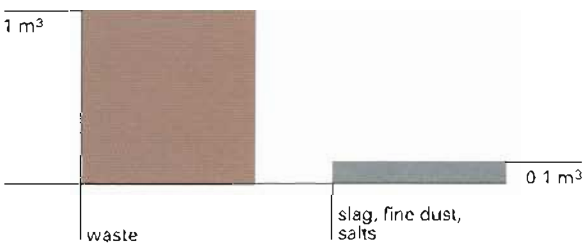
- to generate electricity;
- to produce hot water to supply district heating systems for homes, hospitals, public swimming pools, etc;
- to supply steam for industrial processes;
- a combination of all these uses.

This aspect plays an important role when selecting the construction site for a new incineration plant. In general, if the findings of the environmental impact study prevent the plant being sited near an end-user of steam or hot water, the thermal energy is used solely to generate electricity.

By way of information, the calorific value of a tonne of household waste is equivalent to 200 kg of fuel, 250 kg of coal, 30 tonnes of hot water or 500 kWh of electricity. The heat recovered during incineration can cover 4–6% of the energy needs of the population who produce the waste.

Reducing the volume and weight of waste by incineration

1 m³ of waste is reduced to 0.1 m³ of solid residue



1000 kg of waste is reduced to 300 kg of solid residue

Separation of materials flow

Recent developments in waste – both as regards quantity and quality – plus tighter environmental controls mean we can no longer consider incineration as a simple method for disposing of waste by burning it, with the welcome by-product of energy recovery.

It has been possible to integrate incineration into modern waste management systems by giving priority to the transformation and separation of materials.

Incineration allows complex chemical compounds, such as polymers or paints, to be partially broken down into basic constituents. By optimising combustion and the careful selection of flue-gas treatment procedures, it is possible to minimise the pollutants emitted from the stack: the different residues can then be treated separately using appropriate techniques.

Apart from the treated flue-gas, other matter produced by the plant includes:

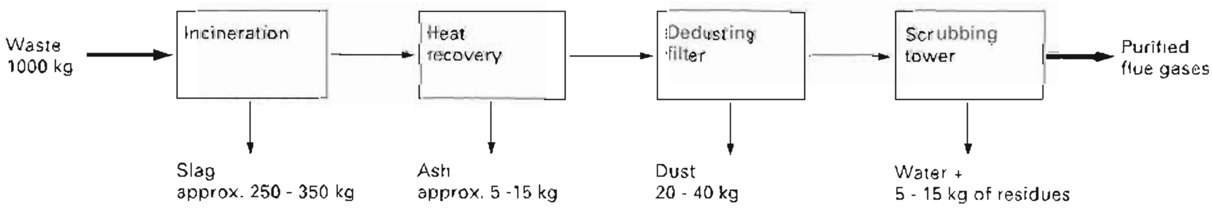
- incineration residues. The mass of slag constitutes, on average, 25% of the original mass of the waste, and just 10% of its original volume.
- dust, known as fly ash, captured in the boiler and by the dust filter.
- flue-gas treatment residues (dried sludge, waste water, residues from the evaporation of waste water).

Rendering residual substances inert

Above all, separating the waste flow enables some materials to be recycled, such as scrap iron, slag, and depending on the flue-gas treatment used gypsum, hydrochloric acid, or industrial-quality salt.

Residual substances must first undergo various treatments before they can be dumped in landfills:
After suitable treatment, the slag can be used as hard core for road construction.

Materials flow separation in an MWT plant equipped with a wet scrubbing system for flue gases



Fly ash contains unacceptable levels of chlorides, sulphates and heavy metals. Current technology offers a number of methods to render the fly ash inert:

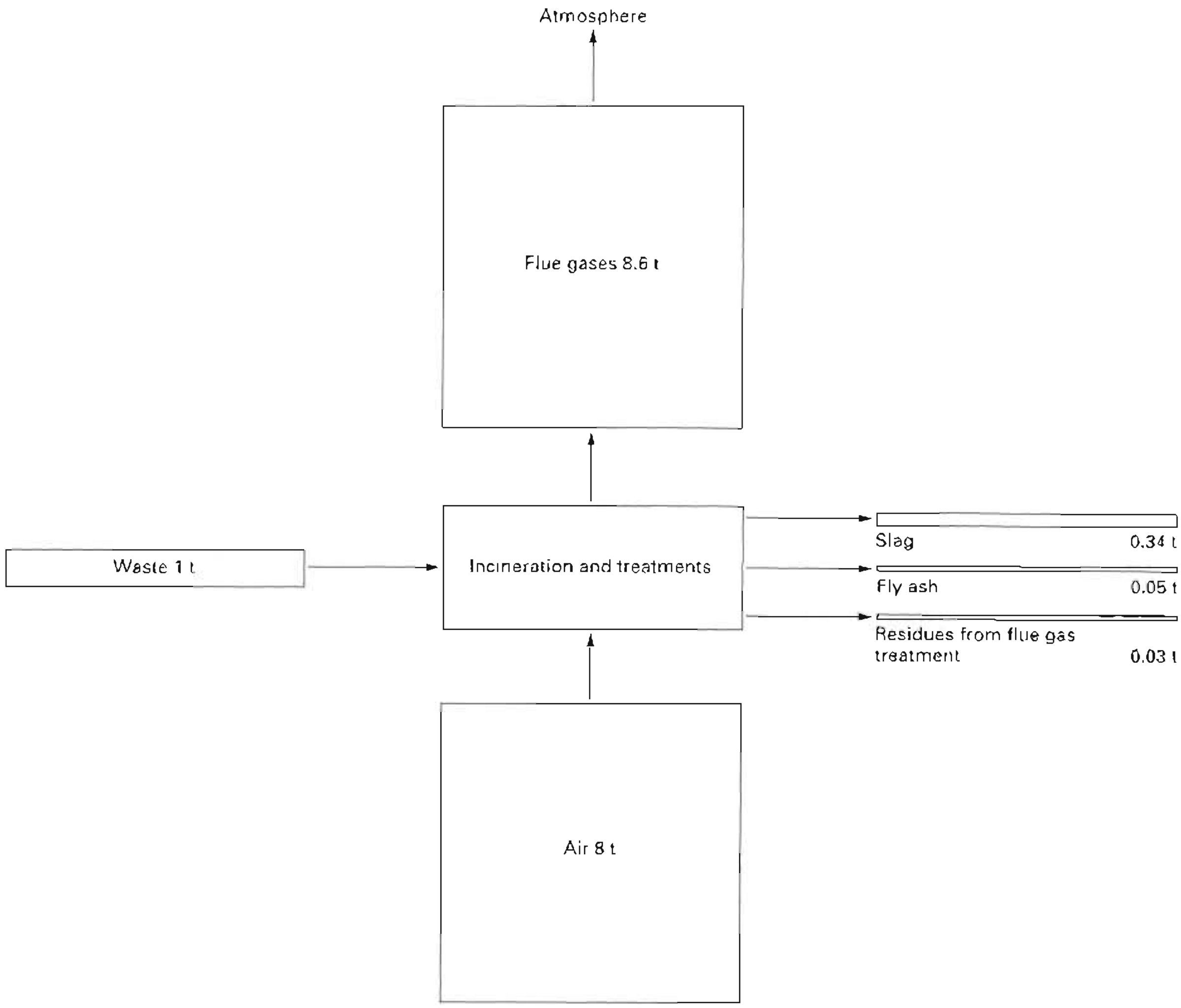
- scrubbing followed by/or solidification with cement
- leaching
- vitrification in an electric furnace
- inertisation in bitumen

Residues from flue-gas treatment (wet scrubbing) only represent a tiny fraction of incinerated waste. These residues contain pollutants such as heavy metals and are classed as toxic waste, which means they should be governed by controlled dumping regulations.

4.3 Basic stages in the design of an MWT plant

The design of a municipal waste treatment plant has to satisfy many different criteria, some of them very complex: the size of the collection area which the plant serves, integration into its physical setting, composition of the waste being treated, proportions of the plant, choice of processes for the various systems (incineration, flue-gas purification, residue treatment), reliability, robustness, optimisation of energy recovery, flexibility and adaptability to constantly changing technologies and regulations, ease of operation and maintenance, compliance with investment and maintenance budgets, etc.

MWT plant: analysis of weights



Administrative constraints and obligations

The construction and operation of MWT plants are governed by licensing procedures particular to each country or region. These procedures impose legal and technical constraints on the various phases of planning, construction, operation and discontinuation of waste treatment activities.

The application for a licence initiates a procedure, that entails in particular a public inquiry, to hear the opinions of all the different parties. Licensing procedures are usually very complex and vary immensely from one country to the next. A description of these procedures is outside the scope of this publication, and is not therefore included here.

Environmental protection regulations stipulate that an environmental impact study must be completed before a new MWT plant is built. The documentation submitted when applying for a license to build and operate an MWT plant is always required to include an environmental impact study whose main aims are:
- to inform the administrative authority issuing the licence for the project;
- to take into consideration the environmental data and concerns associated with the project;
- to propose measures, where necessary, for the elimination, reduction or making good any harmful effects on the environment.

Choice of processes

Nowadays there is a wide range of tried and tested processes, ranging from incineration (grate furnace, shelf furnace, oscillating furnace, fluidised bed furnace, etc.) to flue-gas treatment (dry, semi-wet, wet scrubbing, denitrification, etc.) and residue treatment (vitrification, solidification with cement, washing with acid, etc.).

The basic criteria for choosing the appropriate procedure seem straightforward:
- combustion must be correctly controlled to avoid any transfer of pollution and associated nuisance (in Switzerland, for example, slag must not contain more than 3% unburnt substances);
- flue gases must be treated so that they comply with the maximum emission levels permitted by environmental regulations;
- the energy recovered from the waste incineration process must be sufficient to cover the plant's own energy requirements;
- the residues from the various systems must be collected separately and then treated for subsequent recycling or dumping in a controlled landfill.

Even so, the decision-maker's task is made extremely difficult by the diversity of the procedures available, local economic constraints, obligations towards the operator (who expects reasonable constraints on the operation and maintenance of the plant), the pressure exerted by the partisans of the new "miracle technology", and the moral obligation to support an investment with vision but one that is also sustainable.

Although there are already tens of modern MWT plants in service, there is no standard plant design. A pragmatic approach with the benefit of experience is the only way of finding a model that offers the best compromise. To this end, and as a useful link to the next paragraph, we quote the wording of a resolution passed on 7 May 1990 by the Council of the European Communities on waste management policy. This specifies that the main criterion in the selection of procedures is to make every effort to reduce pollution to levels which, by current scientific standards, are considered to "make use of the most appropriate methods and technologies to guarantee a high level of protection for the environment and public health, taking into account best available technologies not entailing excessive cost".

Choice of investment

In some countries the financial aspect is only of relative importance because each new plant constructed must be capable of achieving "zero pollution" and the investment required to build a new average-sized (150,000 tonnes p.a.) MWT plant can easily exceed ECU 500 million. In other countries, on the other hand, the idea of "taking into account best available technologies not entailing excessive cost" is still a decisive factor when choosing procedures and technologies. In this case, the investment is unlikely to exceed ECU 100 million. Chapter 6 provides more detailed information on cost aspects.

Choice of location

At the moment there are two quite distinct approaches for choosing the site for a new MWT plant. The first is to choose a location well away from town centres or residential areas, preferably near or on old waste dumps, in industrial zones or swamp regions. The second approach attempts to give maximum consideration to the environmental impact study. In this case, a decision may be taken to locate the MWT plant near the centre of town, to limit the nuisance caused by refuse collection trucks and other private vehicles. The environmental and architectural aspects play an essential role here because, apart from ensuring that the plant blends in aesthetically with its setting, controls on emissions, noise, odour and pollution are obviously very important. Although this second approach usually entails a more substantial investment, it also offers significant benefits which are fully exploited in the choice of the site (reduction of transport costs and nuisance, better integration into the environment, proximity to end-users of heat, etc.).

Dimensions of the MWT plant

The capacity of an MWT plant is measured by the thermal power (i.e. energy) produced during the incineration process, which can then be harnessed and converted into steam or hot water by means of a boiler.

The thermal power of an MWT plant is the product of the hourly throughput of incinerated waste multiplied by the calorific value of the waste, i.e. the energy contained in the waste. Given that the lower heating value (H_u) depends entirely on the composition of the waste, forecasts of waste trends are absolutely essential when attempting to calculate the future capacity of the new MWT plant.

Any changes in the composition of the waste to be incinerated in the plant will depend mainly on the waste management policy adopted by local authorities, which in turn requires that environmental policy is coordinated at national level.

Despite major advances in waste analysis in recent years, it is impossible to make accurate forecasts as to the quantity and composition of waste in 5–10 years' time. Such forecasts are made even more difficult by the fact that certain factors have contradictory effects. The quantity of waste to be incinerated should normally increase, because the population is growing and the ban on dumping untreated waste will be extended. Furthermore, new decrees and legislation will come into force in a number of countries which will encourage waste incineration.

However, waste is increasingly being collected separately and recycled thanks to better infrastructures and the greater environmental awareness of the general public. This should lead to a reduction in the quantities of waste being handled. The gloomy economic outlook and the introduction of waste collection taxes should also have an impact on the production of municipal waste. However, bearing in mind that the average H_u of waste will increase between now and the year 2000, the incineration capacity of MWT plants will need to be about 10–15% higher in terms of thermal power.

Impact of changes in calorific values on incineration capacities

The average H_u of waste is a key factor for calculating the size of an MWT plant. At the time when most MWT plants were constructed, the average H_u of waste was between 6,000 and 10,500 MJ/t. In Switzerland it is estimated that the current average H_u of 11,500 MJ/t will climb to 12,600 MJ/t by the year 2000.

With the huge increase in plastic as a component of consumer goods (especially packaging), the average H_u of waste has risen sharply over the last 15 years or so. Sorting waste at source, recycling by composting organic matter and introducing separate collection of glass and metals have led to an increase in the average H_u of the waste to be incinerated. As we already said, the calorific value of synthetic materials is very high, whereas for organic waste it is very low, and virtually nil for glass.

Previous comments about the production of household waste also apply to the H_u, i.e. the bigger a city, the higher the H_u of the waste it produces. Another point worth noting is that the H_u of waste produced in Northern cities is higher than in the South. The main reason for this is that Northerners tend to consume more packaged foods and goods, whilst Southerners consume fresh produce bought in markets or grown in their own gardens.

Loading

Although the dimensioning of every new MWT plant must take into account numerous parameters including those described above, oversizing the treatment capacity will lead to an unsatisfactory business result: annual debt servicing (interest and valuation readjustments) would be spread over too low a volume of treated waste. Bearing in mind the very high cost of modern MWT plants, too much reserve capacity could have a negative impact on the operating quality.

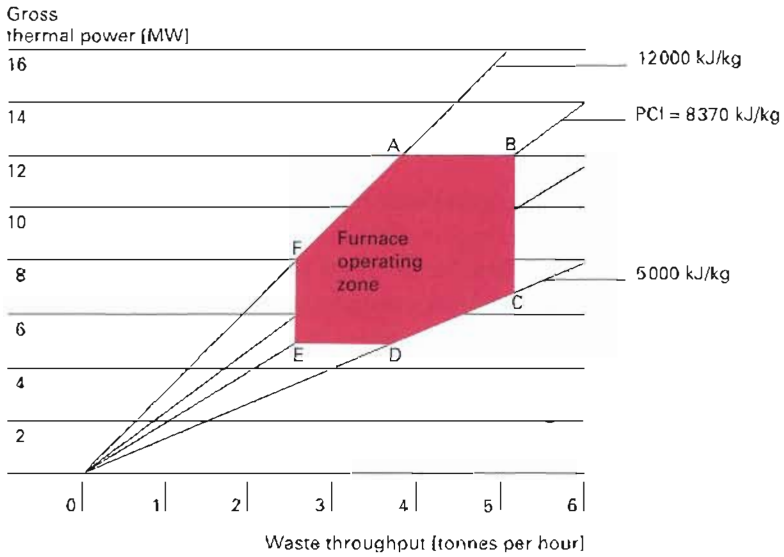
Because of shutdowns – whether scheduled or unscheduled – as a result of general overhauls or repairs, it is impossible for an installation to operate 24 hours a day throughout the year. The availability factor generally aimed for when a project is drawn up is in the region of 85%. This value is theoretical and assumes that a processing line cannot operate more than 7,500 hours a year (8760 hours x 0.85).

As a general rule, the MWT plant is kept running seven days a week to prevent corrosion or premature ageing problems in the installations. To ensure that the plant maintains operation, even at a reduced capacity, for the whole year, MWT plants usually include several processing lines. The service life of an MWT plant is around 20 years.

If there is a serious fault that takes longer to repair, there are generally agreements for the transfer of waste between regions, which also ensures that excess capacity is more evenly distributed and ultimately provides a better return on the capital invested in the construction project.

Combustion diagram

The combustion diagram represents the operational zone of the furnace. The values on the Y axis show the gross calorific value of the furnace in megawatts, while the X axis shows the capacity in terms of mass (tonnes per hour) of incinerated waste.



Combustion diagram of a grate furnace.

The straight lines represent the H_u of the waste to be treated. Point A is the plant's nominal operation. Performance testing is usually carried out at this point (combustion quality, calorific output, treatment of flue gases, consumption, etc.). Tests can also be performed at a minimum operation level to monitor the quality of combustion when waste with a low H_u is incinerated at low temperatures. Obviously the installations must be capable of operating in compliance with technical specifications, within the entire combustion diagram. The shape of the diagram can vary depending on the H_u range of the waste being incinerated, the type of furnace and the plant's constructor.

4.4 Main processes available for waste incineration

The thermal treatment of waste by incineration involves burning the waste in special furnaces suited to the composition, granulometry, calorific value and moisture content of the waste. Combustion must be correctly controlled to avoid any damage to the installations and to ensure complete combustion of the organic matter.

There is no single solution to the problem of incinerating the mountains of waste which we produce every day. In fact, a wide range of options is available for thermal treatment of waste under environmentally sound conditions.

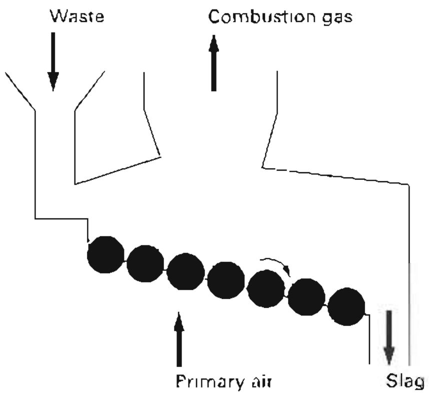
The table below provides an overview of the main types of furnace used, depending on the nature of the waste to be incinerated. There are of course other processes, such as those involving oscillating furnaces, shelf furnaces, pyrolysis, plasma furnaces etc. These technologies go beyond the scope of this report and so we shall limit ourselves to the most commonly used methods. Nevertheless, pyrolysis treatment offers interesting prospects and is therefore described briefly at the end of the chapter.

Main combustion systems for different types of waste

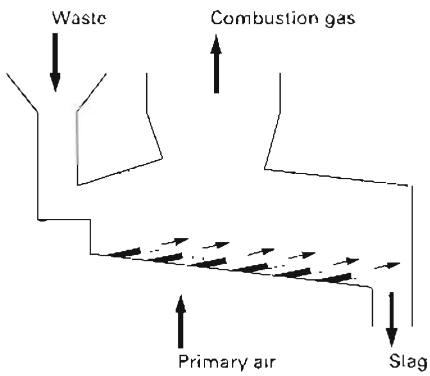
Municipal and similar waste	Industrial and special waste (solids, liquids and pasty), contaminated soil	Dried sewage sludge, used oils and production waste (plastics, wood, etc.)
↓	↓	↓
Grate furnace Fluidised bed furnace	Rotary kiln	Fluidised bed furnace Rotary kiln

Principal types of combustion grates

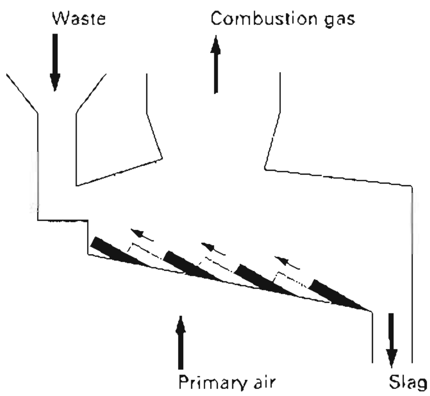
Roller grate



Co-current reciprocating grate



Counter-current reciprocating grate



4.4.1 Combustion grate furnace

The most wide-spread thermal treatment of waste involves incineration on a grate, and this technique has also had the most proven success. For many years, grate incineration has been common for the thermal treatment of municipal and similar waste in solid form. This method is not suitable for incinerating liquid waste or sludge because too much of the waste would fall through the gaps in the grate without being incinerated.

Grate systems are divided into two groups depending on the conveyor method used:
- continuous conveyor grates (e.g. roller grates)
- discontinuous conveyor grates (co-current reciprocating grate, counter-current reciprocating grate)

Roller grate
The combustion bed is situated on a number of rollers arranged one on top of the other in succession to form a grate. The waste is conveyed and stirred by a combination of gravity and the rotary movement of the rollers.

Co-current reciprocating grate
The waste is conveyed and stirred by the alternating movement of the grate bars. With the co-current reciprocating grate, the grate does not have to slope in the direction of the waste flow.

Counter-current reciprocating grate
The waste is conveyed by gravity down the slope of the grate. It is stirred by the bars which move in the opposite direction to the waste flow.

Grate furnace.
Cross-section of the furnace/boiler

1 Charging hopper
2 Feeding device
3 Combustion chamber
4 Combustion grate
5 Recovery boiler
6 Residue removal
7 Removal of grate sifting
8 Removal of fly ash
9 Primary air system
10 Secondary air system

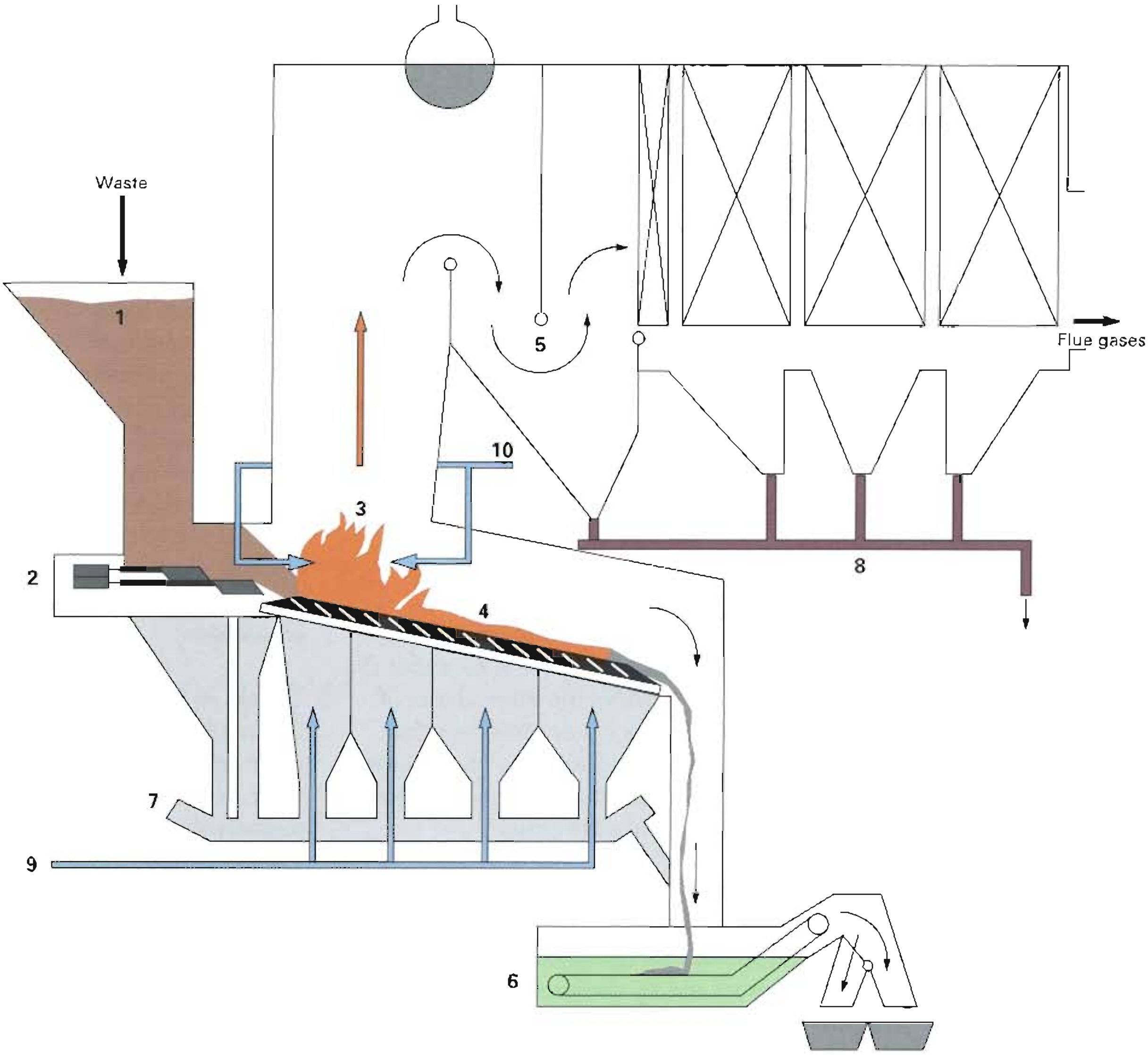
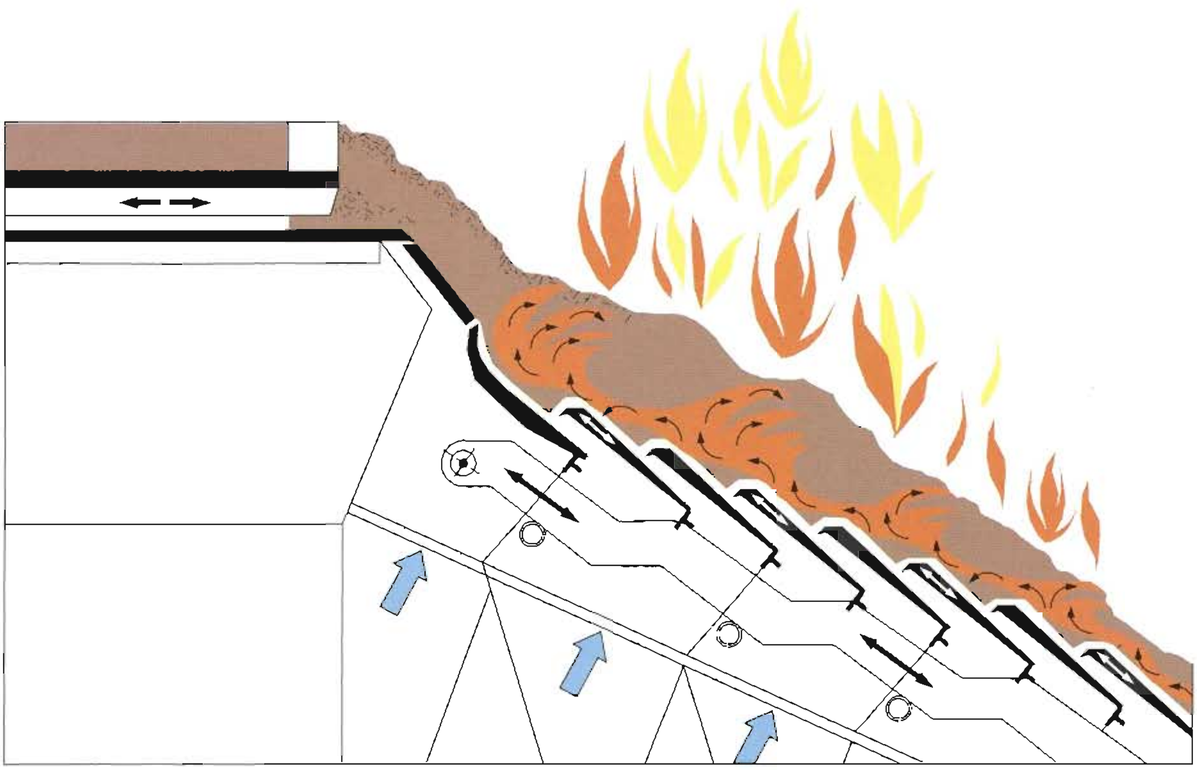


Illustration of a reciprocating grate furnace



Remarks:
Since the first waste incineration plant was constructed in Britain in 1876, many companies have developed and built numerous varieties of grates, some of which no longer exist. At the present time in Europe, the most popular grates are the roller grate (Babcock), the counter-current reciprocating grate (Martin) and the co-current reciprocating grate (Von Roll). Other firms have produced many variants of these basic grate designs.

Different phases of incineration on a grate
A carefully controlled admission of air under the grate (primary air) enables the three phases of combustion to take place, one after the other: drying, degassing and gasification. The gases are fully combusted thanks to a supply of secondary air into the hearth above the grate.

The waste is pushed by the ram feeder as far as the first zone of the grate – the drying zone – where it is spread out and dried by the passage of combustion air and by the intense heat from the flames and the refractory walls of the furnace.

Actual combustion takes place in the second and third zones of the grate by means of the combustion air injected across the grate. In the last zone, combustion is completed and the surplus air guarantees total combustion of the slag. Once the waste has been completely burnt up, the residual slag and ash fall through a shaft into the ram discharger.

4.4.2 Fluidised-bed furnace

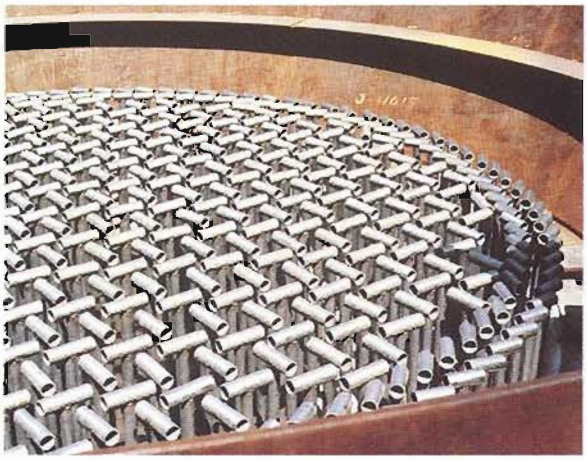
Fluidised-bed incineration is an alternative process to conventional incineration. It involves combustion of matter in a vertical furnace with a layer of sand in its base. This sand is brought into a state of fluidisation by the combustion air injected into the base of the furnace via a large number of nozzles.

Compared with conventional incineration of waste on grates, this technology has the following advantages:

Thanks to the high thermal inertia of the fluidised sand bed (800°C) it is possible to incinerate waste with a highly variable and very low heating value without any significant change in operating parameters.
The properties of this bed, which are similar to those of a fluid, guarantee good efficiency in terms of thermal transmission and a good exchange of matter, resulting in more thorough combustion and enhanced thermal efficiency of the installation.

Because of the lower temperatures, relatively less nitrogen oxides (NOx) are formed. The costs of treating the flue gases can be reduced by injecting dolomite or calcium carbonate directly into the fluidised bed, to partially neutralise the acid pollutants such as SOx and HCl.

The floor of a stationary fluidised-bed furnace showing the nozzles for injecting the combustion (and fluidisation) air



Depending on the degree of fluidisation of the sand bed, a distinction is made between:
• stationary (dense) fluidised-bed incineration;
• circulating fluidised-bed incineration;
• rapid fluidised bed, high-expansion fluidised bed.

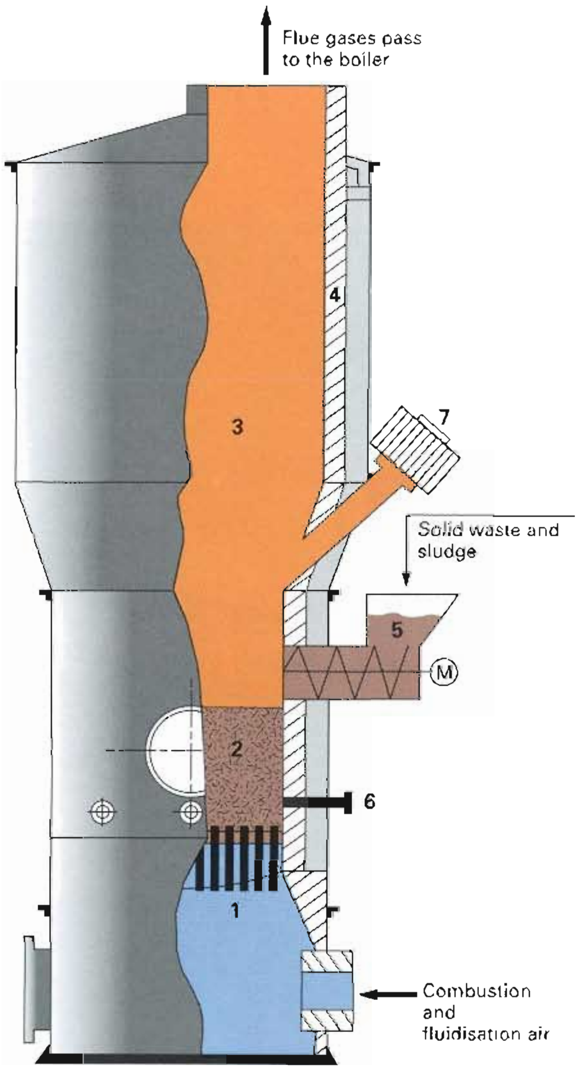
There are also intermediate examples such as the "turbofluidised bed" which combines the advantages of slow and rapid fluidised beds.

Compared to a conventional furnace with a combustion grate, waste incineration in a fluidised-bed furnace has two major drawbacks:
• because of the technical difficulties of removing sizeable residues from the fluidised bed (pieces of stone, metal etc.) the waste must be sorted and shredded before being fed into the furnace;
• to avoid the risk of melting the sand bed, the temperature in the combustion chamber is maintained at approximately 800°C. This means that fluidised-bed furnaces cannot be used to incinerate industrial waste in countries where the minimum combustion temperature must not fall below 1200°C.

Fluidised-bed incineration is used mainly for combustion of waste with a low heating value or which can be easily shredded:
• production waste such as plastic residues, wood chips etc.
• industrial sludge and sewage sludge
• combustible materials obtained from process waste, screened materials, tyres
• used oils, solvents.

Stationary fluidised-bed furnace

1 Fluidisation nozzles
2 Fluidised sand bed
3 Combustion chamber
4 Refractory brickwork
5 Furnace feed
6 Injection nozzles
7 Start-up burner



4.4.3 **Rotary kiln**

Rotary kilns are essentially used for incinerating hazardous waste in liquid, pasty or solid form, and for thermal treatment of contaminated soils. They are not used for incinerating municipal waste, but since every one of us produces special waste (batteries, used oils, expired medicines, paints etc.) we believe it is worthwhile summarising the methods of eliminating these dangerous wastes.

The rotary kiln comprises the following elements:

waste feed devices
for waste in solid, pasty and liquid form and in barrels.

front wall
The primary combustion air is admitted via a ring system, at the same time cutting off the air so as to seal off the rotary kiln. The front wall contains a removable chute with its own water coolant circuit.

Rotary kiln in an incineration plant for hazardous waste

rotary kiln

The rotary kiln comprises a steel cylinder which is slightly inclined (by approximately 3°) with an internal lining of refractory bricks and an external drive system. The materials to be incinerated are transported from one end of the furnace to the other by a combination of the slight slope and the rotary movement.

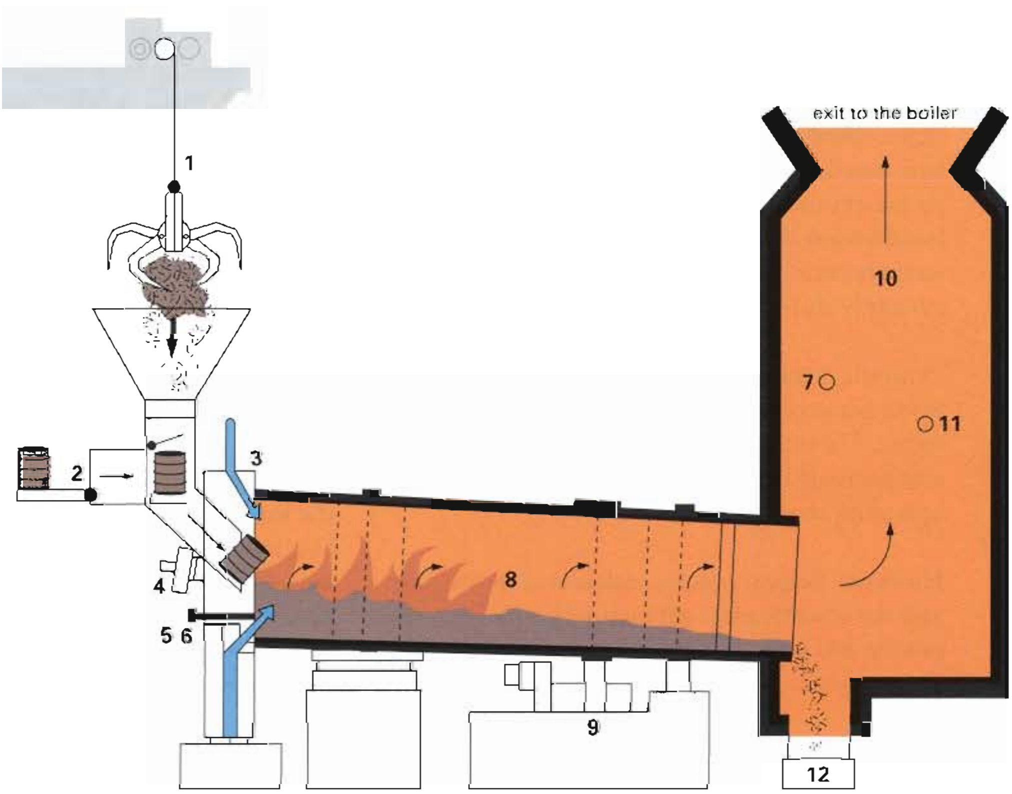
secondary combustion chamber

This section of the furnace is lined with refractory bricks and is specially designed to ensure complete combustion of the gases. It narrows at the point where the secondary combustion air is admitted at high speed to ensure that the gases are thoroughly mixed.

Drying, degassing, gasification and combustion essentially take place in the rotary kiln. The gases are burnt up in the secondary combustion chamber which is equipped with booster burners to maintain the correct combustion temperature at all times.

The main characteristics of rotary furnace incineration are:

- good flexibility to deal with different types of waste;
- high combustion temperature;
- slag removal in the dry or molten state;
- prolonged residence time (4 seconds) of combustion gases at high temperature (1200°C).



Rotary furnace with waste feed system and post-combustion chamber

1 Feeding by means of overhead travelling crane
2 Barrel feeding system
3 Primary air system
4 Booster burner
5 Injection of liquid waste
6 Injection of pasty waste
7 Secondary air system
8 Combustion chamber
9 Kiln drive system
10 Secondary combustion chamber
11 Waste water injection
12 Slag removal

4.4.4 Pyrolysis furnace

The incineration of municipal waste in traditional grate furnaces is based on proven technology, but there is limited scope for further performance improvements. The new requirements which waste treatment plants now have to satisfy have prompted designers to steer their research towards new methods. Despite the excellent environmental performance of modern MWT plants, they have been criticised for producing excessive quantities of toxic residues and for being too expensive.

A great deal of research has been carried out over the past 30 years into the use of pyrolysis technology for treating waste. Pyrolysis involves submitting a product (waste materials, coal etc.) in an oxygen-deficient atmosphere to temperatures in the region of 500°C in order to convert it into gas, hydrocarbons and carbonised residues. The gas produced in this way is not burnt (lack of flames) and thus has a certain H_u. The original idea was to recover useful materials such as fuel, coke etc. in so far as possible and to utilise the energy released by the pyrolysis gases. Many processes based on this concept have been effected and tested in pilot installations. However, pyrolysis has yet to establish itself. Only a few special installations designed for very specific types of waste (plastics, tyres, electronic components) are currently in service.

Pyrolysis is less suitable for the treatment of waste materials as heterogeneous as municipal refuse. Pre-treatment (e.g. sorting, shredding or compacting) is necessary to meet the minimum operating requirements.

However, despite adverse experience in the past and the uncertainties surrounding pyrolysis, the process has by no means been abandoned. The advantages are such that many firms have turned their attention to pyrolysis. To avoid being left behind, some designers of conventional MWT plants have developed a combined pyrolysis/combustion method for treating mixed heterogeneous waste. The installations have the attraction of combining proven conventional technologies for degassing waste. The pyrolysis gases are burnt in a post-combustion chamber. Slag is vitrified at a high temperature (>1200°C) to produce an inert product which can be re-cycled without further treatment.

Thermoselect pyrolysis installation for treatment of municipal waste

The most innovative aspect of this process is that a car-crusher is used to compress unsorted waste to a tenth of its original volume before it is introduced into the degassing channel. The major advantage of this operation is that a large part of the oxygen contained in the waste is extracted (remember that degassing must be carried out in an oxygen-deficient atmosphere).

The very dense mass of waste is continuously pushed into the heated degassing channel in which it is dried at 600°C and organic matter is carbonised. At the end of the channel, the degassed waste falls into a high-temperature reactor where organic substances are broken down into their basic components at a temperature of 2000°C. Reaction residues accumulate in the bottom of the reactor in the form of a vitrified product and scrap metal. Metal must be removed from this residue before it can be re-cycled e.g. as hardcore material.

The admission of oxygen into the reactor leads to the formation of a synthesis gas composed of carbon monoxide, hydrogen, water vapour and carbon dioxide. This gas is rapidly cooled to 90°C by the injection of water upon emergence from the reactor to prevent the formation of dangerous substances such as dioxins and furans. The next phase involves treatment in scrubbing towers, where compounds of sulphur and other pollutants are captured or neutralised. The energy contained in the synthesis gas is used to generate electricity and to heat the degassing channel.

Compared with incineration in a conventional furnace, this process has the following advantages:

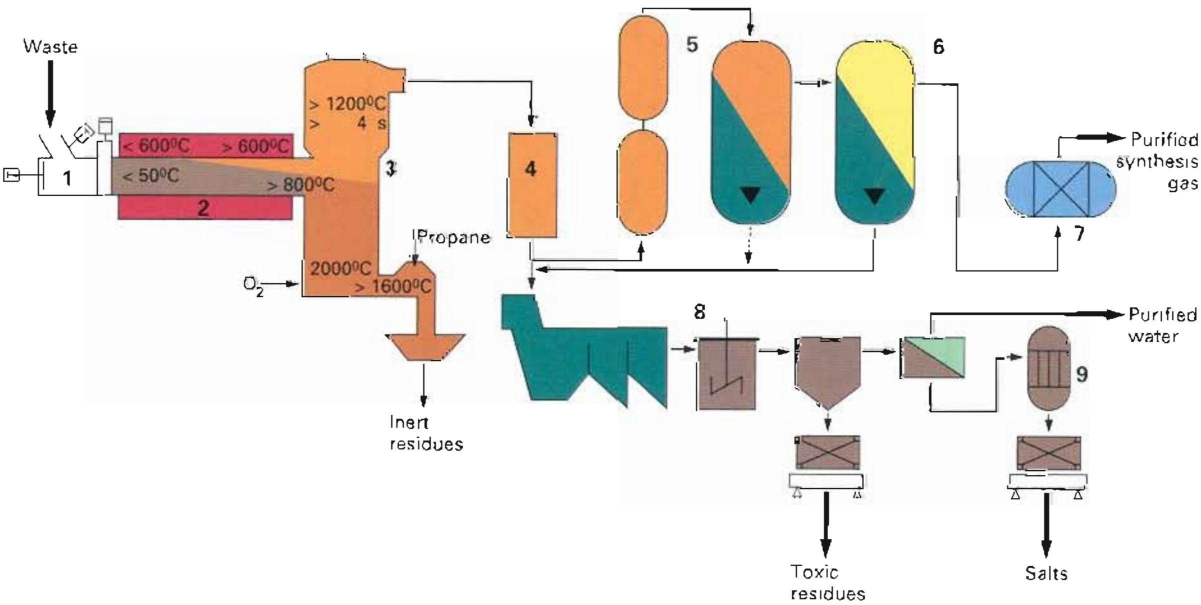
- a small volume of flue-gas is produced, containing significantly less pollutants;
- there is minimal production of toxic residues requiring controlled disposal or special treatment;
- the system is more compact and in principle less expensive.

Despite these considerable advantages, one should not overlook the drawbacks of the process, which are essentially as follows:

- safety problems due to high temperatures, the risk of explosive gas compounds and matter subject to high stresses;
- low overall thermal efficiency;
- uncertainties regarding the efficiency and availability actually attainable with an industrial-scale plant;
- difficulties in estimating operating and maintenance costs (rapid wear of refractory, burner nozzles, etc.).

Thermoselect pyrolysis installation

1 Crusher
2 Degassing channel
3 Reactor
4 Quench
5 Gas scrubbing towers
6 Cooler/dryer
7 Activated carbon filter
8 Treatment of gas scrubbing water
9 Evaporation



4.5 Flue-gas treatment

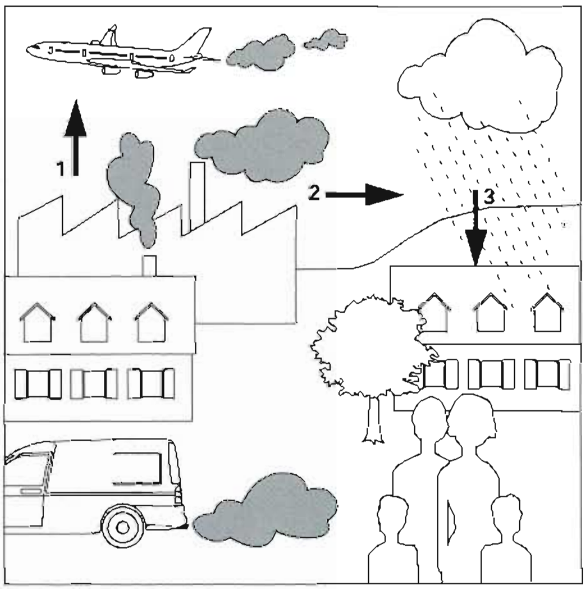
The main problem of waste incineration is the production of flue gases laden with dusts and all manner of pollutants, especially acids, nitrogen oxides and heavy metals, which must be eliminated by means of flue-gas treatment systems.

The nature and quantity of the pollutants contained in the flue gases depend on the composition of the waste, the combustion system and the incineration conditions.

The air quality controls that have to be complied with are nothing new, nor are they a passing fashion: they represent a basic requirement for man and the environment.

Incineration has long been regarded as one of the main causes of air pollution. This explains the hostile response and adverse public opinion every time a new MWT plant is constructed.

Three aspects of air purity



1 Emission: emission of pollutants
2 Transmission: dilution, transport and transformation of pollutants
3 Immission: concentration of pollutants damaging to humans and the environment (dusts and rain)

4.5.1 Formation of pollutants in combustion gases

The table opposite summarises the pollutants present in combustion gases from municipal waste incineration and some of the base materials from which they originate.

4.5.2 Pollutant concentrations in untreated flue gases

In view of the heterogeneous nature of municipal waste, the composition of the combustion gases and thus the concentration of pollutants in these gases vary widely. Treatment of the flue gases produced by MWT plants is therefore significantly more complex than in, for example, coal or gas-fired thermal power stations.

4.5.3 Emission controls

It is, of course, impossible to show in a single table all the emission limits permitted in individual countries. The table opposite gives an idea of the performance levels which must nowadays be met by flue-gas treatment systems in European waste treatment plants. Clearly these values are not definitive and they tend to evolve with changing environmental regulations and technological developments.

Pollutants present in combustion gases from waste incineration

Category	Substance	Origin
Dusts	soot, ash, salt	all wastes
Gases	HCl (hydrochloric acid)	PVC, cooking salt
	SO_2 (sulphur dioxide)	paper, dyes, sludge, rubber
	HF (hydrogen fluoride)	insulators, Teflon, sprays, refrigerants
	NO_2 (nitrogen oxides)	textiles, nylon, proteins, secondary reactions
	HBr (hydrogen bromide)	electronic components, non-flammable fabrics
Heavy metals	Pb (lead)	batteries, paints, curtains
	Zn (zinc)	batteries, paints, galvanised products
	Cd (cadmium)	batteries, synthetic fabrics, inks
	Hg (mercury)	batteries, thermometers, amalgams
Organochlorines	dioxins	wood chips, secondary reactions

Pollutant concentrations in untreated flue gases

Pollutant concentrations in untreated flue gases

Substance	Range			Unit
H_2O	10	–	18	Vol. – %
CO_2	6	–	12	Vol. – %
O_2	7	–	14	Vol. – %
CO	20	–	600	mg/Nm³
HCl	400	–	1 500	mg/Nm³
HF	2	–	20	mg/Nm³
SO_2	200	–	800	mg/Nm³
NO_x	150	–	400	mg/Nm³
Dioxins / furans (TE)	1	–	15	ng/Nm³
Dusts	800	–	15 000	mg/Nm³

Authorised emission limits at the stack outlet of MWT plants

Emission limits

	LRV 91	17.Blm.Schv	RV 89	EU MWT plant	EU MWI plant
	CH	D	NL	EU	EU
Dusts	10	10	5	30	5
HCl	20	10	10	50	5
HF	2	1	1	2	1
SO_2	50	50	40	300	25
NOx	80	200	70	–	–
Hg	0.1	0.05	0.05	0.2 (Hg+Cd)	0.05
Cd	0.1	0.05	0.05	0.1	0.05
Sum of heavy metals	1	0.5	1	1/5	0.05
CO	50	50	50	100	5
C tot	20	10	10	20	50
Dioxins TE (ng)	–	0.1	0.1	–	0.1

4.5.4 Principal methods of flue-gas treatment

Flue-gas treatment involves physical separation of solid matter (dusts, fly ash, salts) and chemical separation of gaseous pollutants (HCl, SO_2, HF, NOx and certain heavy metals). There are essentially three different technologies currently used for this purpose. These are as follows:

Dry scrubbing
In this process, a dry neutralisation agent in the form of lime ($Ca(OH)_2$) or limestone is sprayed in a counter-flow system in a reactor. Contaminants are transferred from the gas to the surface of solid particles.

The pollutants (HCl, SO_2 and HF) absorbed on the surface are converted into other substances (calcium salts), but the interior of the particles is not altered by this transfer. This means that the larger the particle, the greater the loss of absorbent.

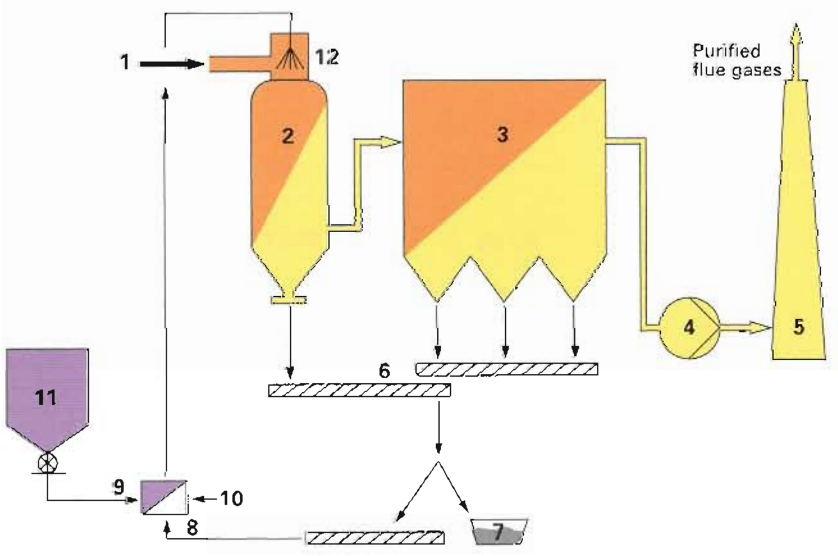
Dedusting of flue gases always takes place after the neutralisation stage. In this way it is possible to simultaneously capture the dust and ash from combustion, the reaction products and the unreacted lime particles.

One of the drawbacks of this process is the high quantity of reagent needed for the reaction (the stoichiometric ratio is greater than two): more than half of it ends up in the residue without having contributed to the flue-gas neutralisation process. Furthermore, dedusting must be carried out using a bag filter as this greatly improves the relatively modest efficiency of the dry scrubbing process (the dusts and reagents adhere to the filtration fabric and increase the duration of contact with the flue gases to be treated).

Capturing the heavy metals present in the flue gases in their gaseous and aerosol form remains a problem, however, since these elements cannot be neutralised by the lime nor intercepted by the filters. Installing a heat exchanger at the intake of the flue-gas treatment system in order to condense certain gaseous heavy metals normally carries risks of corrosion and fouling without guaranteeing satisfactory results.

Schematic diagram of flue-gas treatment by dry scrubbing

1 Flue gases coming from the boiler
2 Reactor
3 Filter
4 Fan
5 Stack
6 Dust removal
7 Residue bin
8 Recycled lime
9 New lime
10 Compressed air
11 Lime silo
12 Injection of lime



Semi-dry scrubbing

This process is a variant of dry scrubbing. It neutralises the acid pollutants contained in the flue gases and cools the flue gases by injection of water to help the heavy metals condense.

It involves spraying the lime in dissolved form (lime milk) in an atomiser. The particles which, in the first instance, help cool the flue gases are reduced to the saturation limit of the absorbing agent by evaporation of the excess water. It is then that actual transformation of matter from the gas phase to the fluid state takes place. The residual water continues to evaporate until only a totally dry, pollutant-laden particle remains. The heavy metals are condensed on particles of dust and neutralisation products which are present in the flue gases.

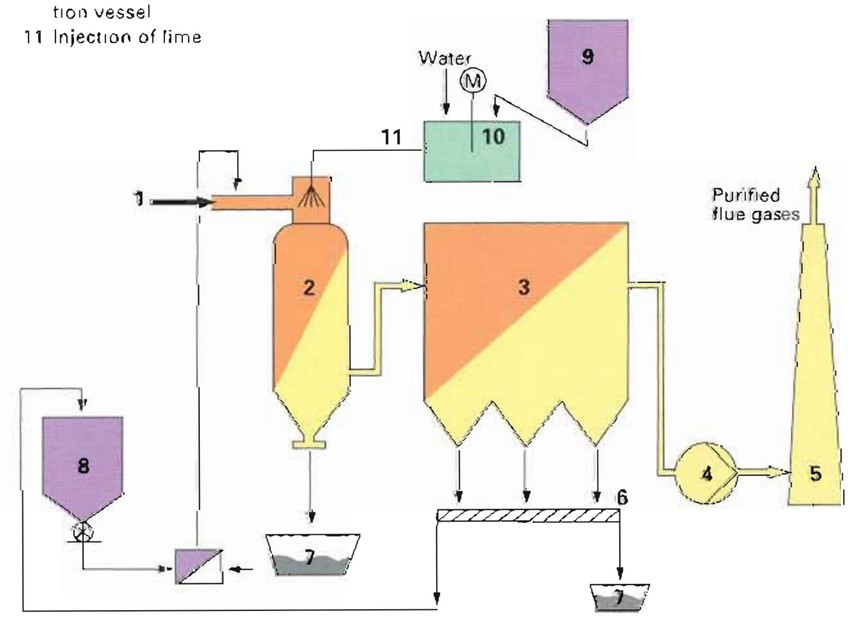
All these solid particles are captured in a dedusting filter positioned downstream of the reactor. The filters used in this flue-gas treatment system are bag filters. Compared with electrostatic filters, these filters have the advantage of improving the overall efficiency of the treatment system, since the flue gases are brought into contact with the still active neutralisation product which is deposited on the filter fabric.

As with dry scrubbing, the removal of large quantities of filtered residues poses serious problems since these are classed as toxic wastes in most countries. Therefore they must either be taken to a controlled dumping facility for dangerous wastes or undergo specialised and costly treatment.

Because of the serious technical drawbacks and, above all, the low efficiency of dry and semi-dry scrubbing, flue-gas treatment systems based on these methods are hardly in operation in countries with stringent environmental controls, such as Switzerland or Germany.

Flue-gas treatment by semi-dry scrubbing

1 Flue gases coming from the boiler
2 Reactor
3 Filter
4 Fan
5 Stack
6 Dust removal
7 Residue bins
8 Recycled lime silo
9 New lime silo
10 Lime milk preparation vessel
11 Injection of lime



Wet scrubbing

This process involves removing pollutants from the flue gases by intensive scrubbing with water. These systems deliver the best results in terms of flue-gas treatment, as they are effective even without chemical reagents.

To avoid fouling problems in the scrubbing installations, the flue gases must be dedusted on leaving the boiler kiln. Electrostatic precipitators are normally used for this. Bag filters are less commonly used, being more sensitive to flue-gas temperatures which are still high at the output of the boiler. Furthermore, in this process the filter does not have to perform any neutralisation function.

Filtered residues from flue-gas treatment by semi-dry scrubbing present a real disposal problem.

Flue-gas treatment systems based on wet scrubbing include:

- an initial conditioning stage called a "quench" in which the flue gases are saturated by injection of a large quantity of water;
- a multi-stage scrubbing tower in which pollutants are extracted from the flue gases in gaseous form. Heavy metals in the form of aerosols are condensed and then carried away with the scrubbing water.

Waste water from the flue-gas treatment installation contains hydrochloric acid, sodium sulphate (where sulphur oxides are neutralised with caustic soda), heavy metals and fine dusts.

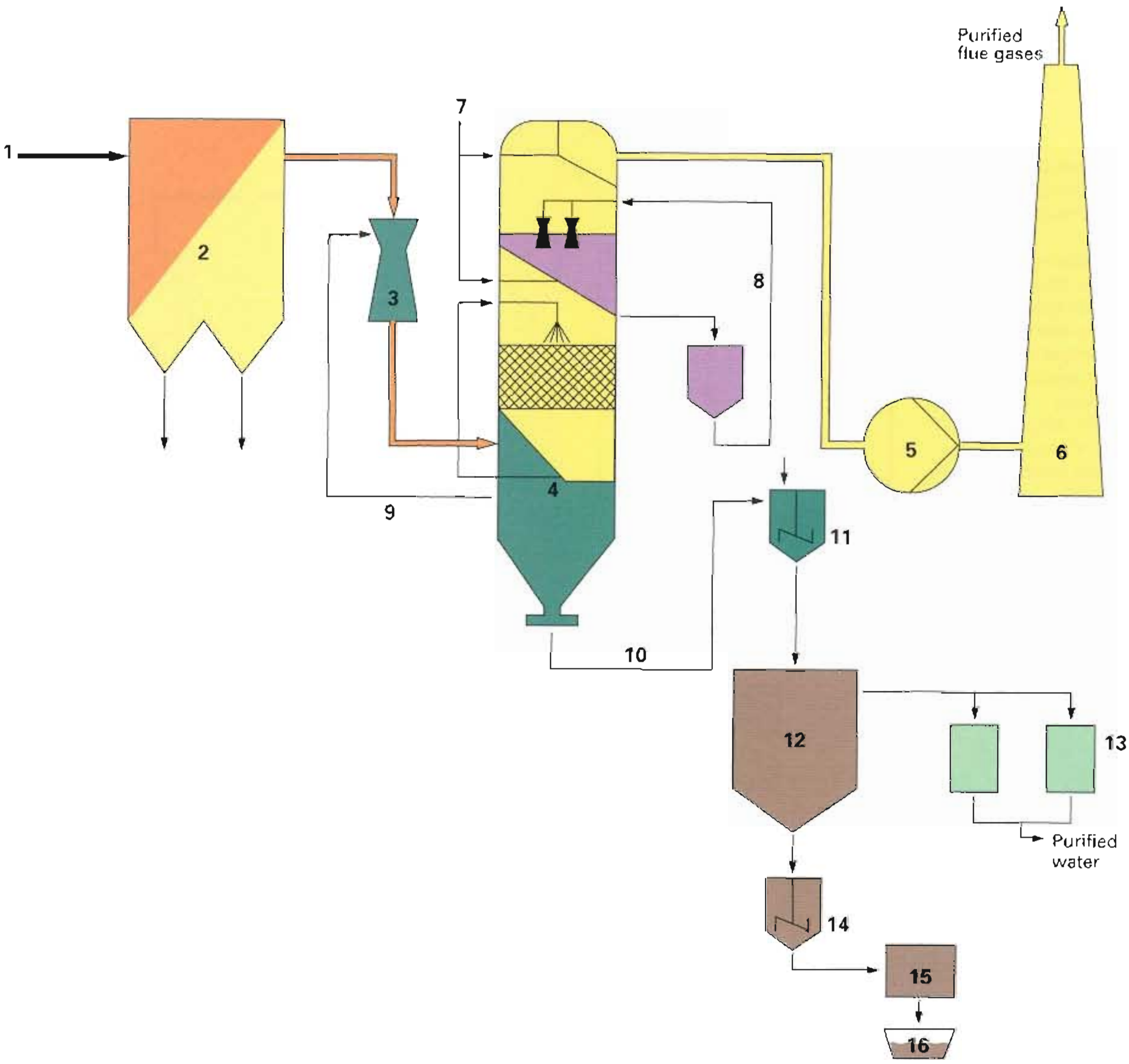
According to current water pollution regulations, these effluents may not be discharged into the natural environment. In view of their very high acidity and heavy metal content, they also are prohibited from discharging into a sewerage system leading to a municipal sewage plant. As a result, part of the scrubbing effluent is drawn off and then led to the internal effluent cleansing plant, where the acids are neutralised by the addition of lime milk and form gypsum ($CaSO_4$), sodium chloride (NaCl) and some $CaCl_2$. The heavy metals contained in the effluent are flocculated and precipitated to form insoluble sludges in the water. These sludges are finally separated in a filter press and the pH of the water is adjusted before it is discharged into the drainage system or rivers.

Where effluent discharge is either undesirable or prohibited, it is possible to bypass the effluent cleaning plant. This is referred to as "effluent-free wet scrubbing". The flue gas scrubbing water is directed to the top of the gas treatment system where it is evaporated in a dryer/atomiser situated between the boiler and the dedusting filter. The considerable heat of the flue gases is used to crystallise the salts contained in the scrubbing water. These salts are partially recovered at the base of the dryer and the remainder is intercepted during the dedusting of the flue gases carried out prior to scrubbing.

Wet scrubbing of the combustion gases has major advantages over other processes:

- maximum capture of pollutants (HCl, HF, SO_2, heavy metals)
- selective capture of individual pollutants is possible
- extremely low residual emissions
- almost stoichiometric consumption of chemical products
- minute quantities of residue.

In view of increasingly stringent air pollution controls, flue-gas treatment systems using wet scrubbing are becoming imperative in many countries.



Wet scrubbing of flue gases with treatment of scrubbing water

1 Flue gases coming from the boiler
2 Dust filter
3 Quench
4 Scrubbing tower
5 Fan
6 Stack
7 Water
8 Caustic soda
9 Water from the first stage
10 Drawing off used water
11 Neutralisation
12 Settling tank
13 Sand filters
14 Sludge thickener
15 Sludge press
16 Toxic residues

4.5.5 NOx reduction (denitrification)

Certain countries have imposed limits on nitrogen oxide emissions. This means that MWT plants must be equipped with systems for denitrifying the combustion gases (i.e. NOx reduction systems). Using such measures, it is possible to reduce the concentration of nitrogen oxides in the flue gases at the output of the stack to 80 mg of NOx/Nm³.

At present the two most common processes are:

Selective Non-Catalytic Reduction (SNCR) method

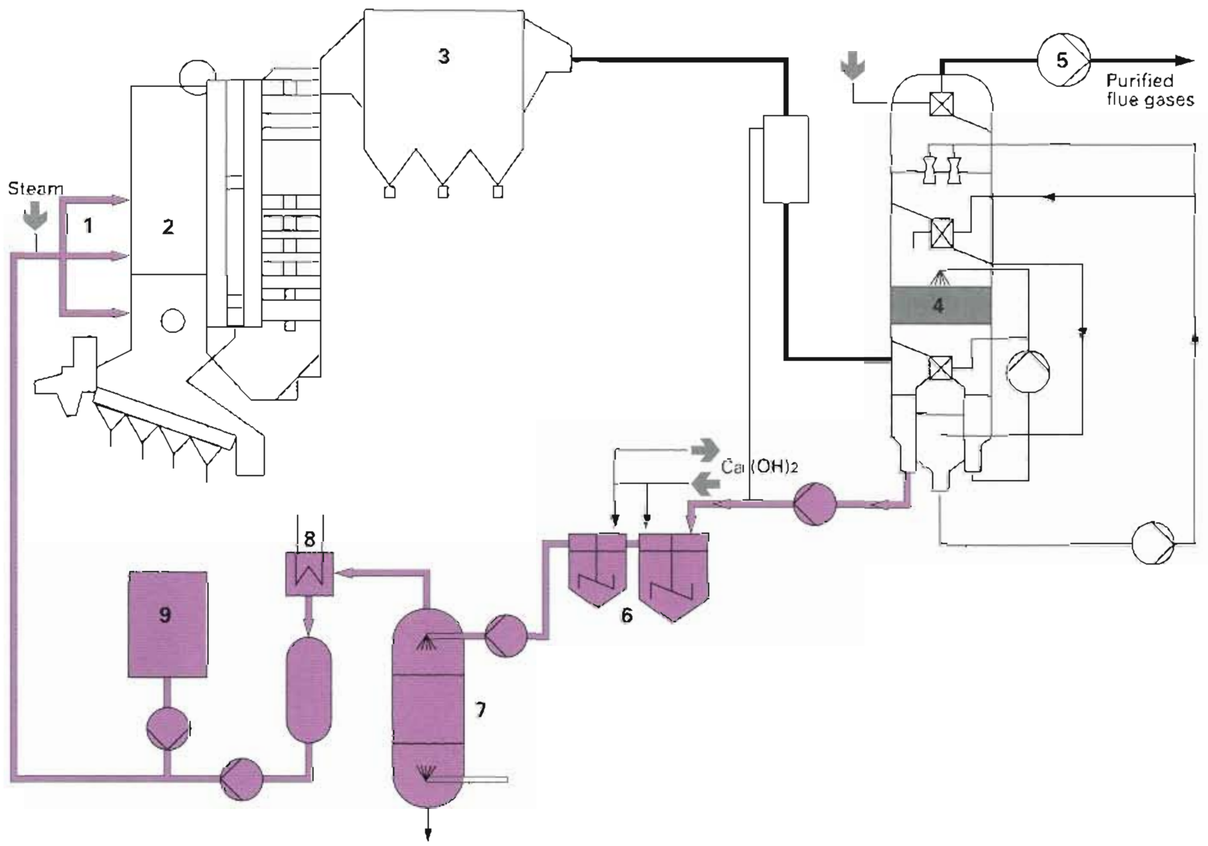
Selective non-catalytic reduction is a method for the thermal reduction of NO (nitrogen oxide) by NH_3 (ammonia). To reduce the nitrogen oxide content of the combustion gases, ammonia is injected in the form of an ammonia solution (NH_3) into the first passage of the boiler. At temperatures in the region of 900°C, the nitrogen oxides (NOx) are reduced to give N_2 and H_2O. The excess ammonia carried by the flue gases is recovered in separation columns. The major difficulty with this process is the strong odour of ammonia that pervades the area surrounding the installations.

Selective Catalytic Reduction (SCR) method

Reduction of the nitrogen oxides NO and NO_2 in the combustion gas, called selective catalytic reduction, takes place when a solution of ammonia is added to the gas as a reducing agent and when this mixture is fed into a catalyser where the nitrogen oxides and the ammonia are converted into nitrogen and water vapour.

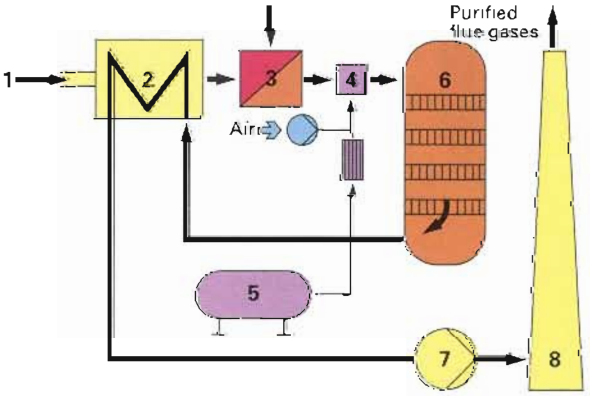
Schematic diagram of denitrification by the SNCR method

1 Injection of ammonia solution
2 Kiln combustion chamber
3 Dedusting filter
4 Flue-gas scrubbing tower
5 Extractor fan
6 Treatment of flue-gas scrubbing water
7 Stripper
8 Condenser
9 Ammonia reservoir



The catalyser is normally a complete catalytic assembly of honeycomb design made from activated titanium dioxide as the basic ceramic material, with catalytically activated inserts that vary depending on the manufacturer. The optimum operating temperature for the catalyser is between 320°C and 350°C.

For reasons of economy, the flue gases leaving the scrubber at approximately 60°C are reheated in two stages. In the first stage, they are reheated to between 290 and 320°C in a heat regenerator where they flow in the opposite direction to very hot denitrified gases. In the second stage, a burner or a heat exchanger raises the temperature by a further 30°C .



Schematic diagram of denitrification by the SCR method

1 Arrival of flue gases from the flue-gas scrubber
2 Preheater
3 Booster burner
4 Ammonia injection
5 Ammonia reservoir
6 Catalyser
7 Extractor fan
8 Stack

4.5.6 Dioxins and furans

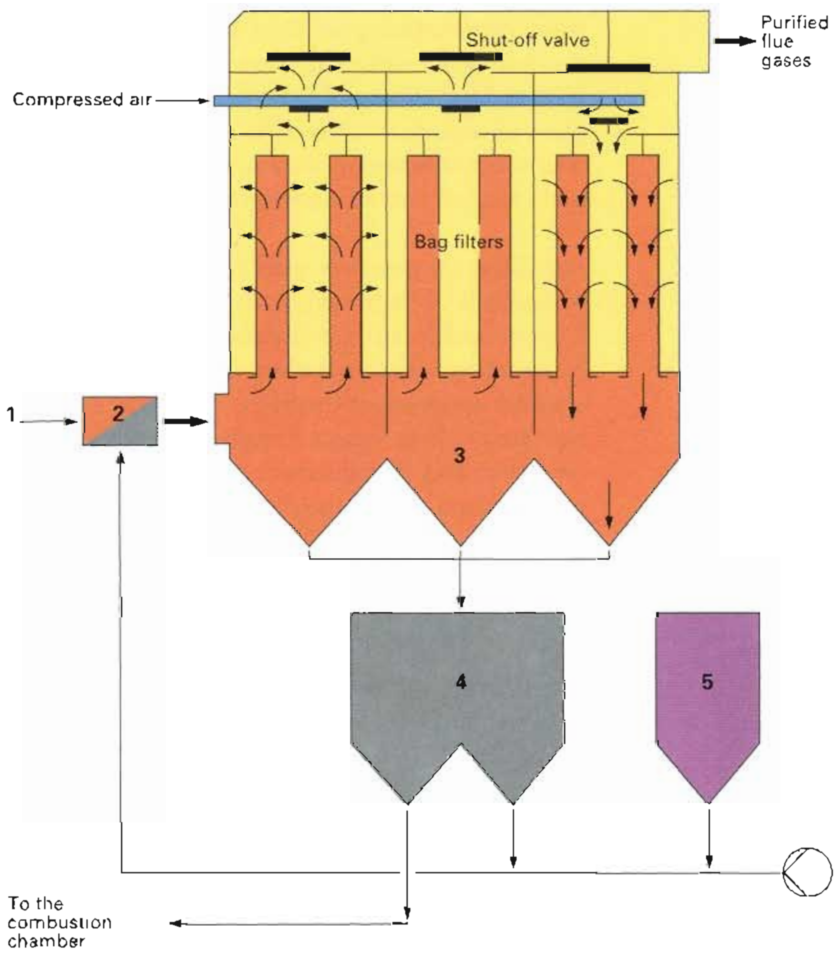
Studies have shown that minute traces of complex components called organochlorines are formed during the incineration process. These are made up of combinations of hydrogen, chlorine and oxygen. Hundreds of different combinations exist, but the best known are dioxins (PCDD) and furans (PCDF) (see p.92). These products do not exist in nature and in principle are not manufactured commercially. They occur in MWT plants after combustion. They are formed mainly by recombination from unburnt residues of fly ash, in a temperature range between 250 and 400°C.

At the present time, only a few countries lay down emission limits for dioxins and furans (in Germany, their concentration is limited to 1 ng/Nm^3). The concentration of dioxins in waste combustion gases is so tiny that constructors have great difficulty measuring them: they have to filter thousands of cubic metres of flue gases to capture a measurable quantity of dioxins. The concentration of dioxins and furans in flue gases is a few tens of a nanogram.

Bag filters are generally used to reduce the concentrations of these pollutants in the flue gases. Dioxins and furans are adsorbed in the bag filter by injecting activated carbon into the flue-gas channel upstream of the filter. The particles of activated carbon form a filtering layer on the filter fabric, and the adsorbent properties of the carbon cause part of the dioxins and furans, in the gaseous state, to be captured and then removed along with the dust.

The bag filter is installed at the end of the conventional flue-gas treatment systems. Its purpose is to reduce all residual emissions (mercury, dioxins, heavy metals, dust) to the limit of detectability. A fixed-bed activated carbon adsorber can be used as an alternative to a bag filter.

Adsorbent bag filter



1 Arrival of flue gases from scrubbing system
2 Injection of activated carbon
3 Bag filter
4 Dust silo
5 Activated carbon silo

4.5.7 Outlook

State-of-the-art technologies make it possible to intercept all pollutants present in flue gases produced by the combustion of municipal waste and to reduce their concentrations to minimal or almost undetectable levels. As a result, certain operators have claimed that their MWT plants actually purify the air in their towns and cities.

The next stage, which has already been reached in some countries, is to develop flue-gas treatment systems which limit the quantity of residues requiring disposal to just a few grams per ton of incinerated waste. In such systems, hydrochloric acid or gypsum is produced from the HCl and SO_2. Heavy metals such as zinc and mercury can be recovered, or industrial quality salt can be produced in an installation for evaporating the flue-gas scrubbing effluent. However, the additional investment needed to attain these performance levels is so large as to make these recycled products far too expensive to be marketed commercially.

The biggest changes in the field of flue-gas treatment may well come from new methods of thermal treatment of waste such as pyrolysis or plasma furnaces.

4.6 Treatment of incineration residues and flue gases

Modern waste treatment complexes are able to separate the flow of materials. This has the advantage that each material flow can be treated in an appropriate manner and all pollutants can be concentrated within a reduced volume of residue at the end of the chain.

The residues produced at the various stages of treatment are as follows:

- slag, which is the combustion residue recovered at the output of the furnace;
- dust and fly ash carried along by the combustion gases and intercepted by the dedusting system and, to some extent, under the boiler;
- the flue-gas treatment residues which vary according to the processes used.

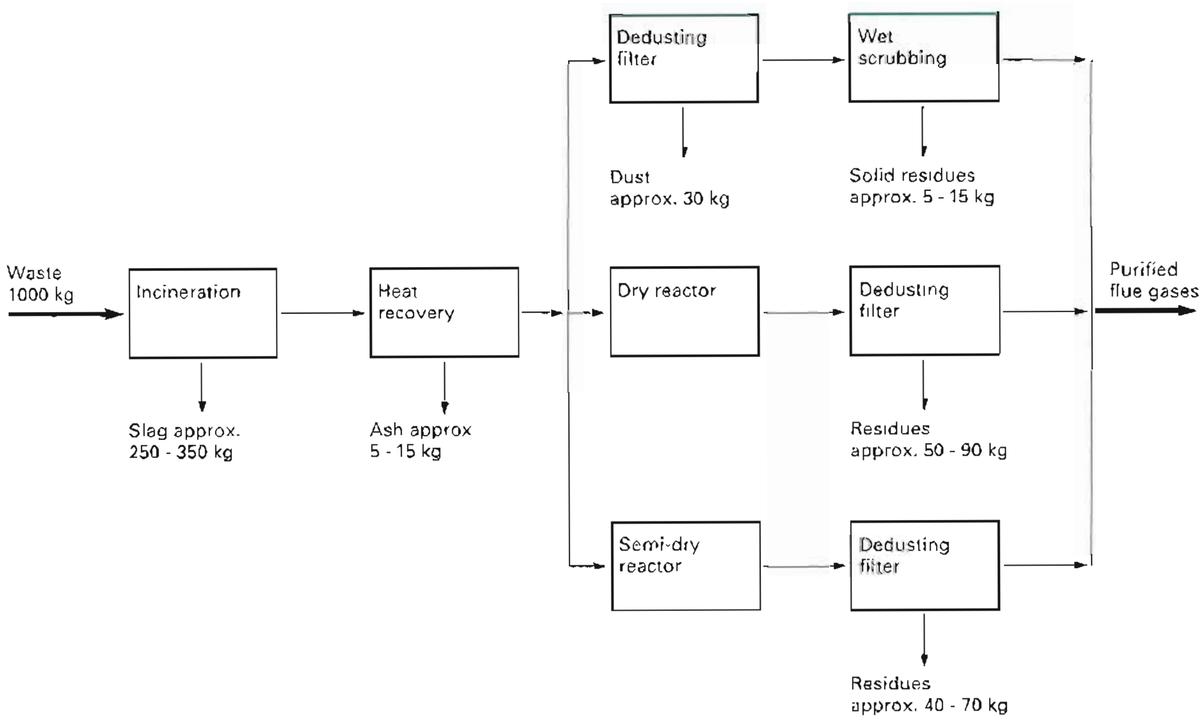
Flue-gas treatment plants using dry or semi-dry scrubbing produce residues containing ash, soluble salts, chemical reagents and heavy metals.

In wet scrubbing systems, the pollutants are trapped in the scrubbing water which is purified in the scrubbing tower to produce a solid residue containing a high concentration of toxic substances.

All these residues, resulting from different stages of waste treatment, must be treated so that they can be reutilised or finally disposed of without posing any long-term danger to the environment.

On the MWT site, these residues must be stored separately and deposited in impervious containers protected from rain and wind, ensuring that any run-off water is collected.

Production of residues in different flue-gas scrubbing systems



4.6.1 Slag

The slag collected at the output of the furnace has the appearance of a greyish gravel and is made up of all types of materials such as glass, stones, non-ferrous metals, iron, salts, unburnt organic matter (2–5% by weight) and traces of heavy metals.

In the field of waste treatment, opinions vary concerning the classification of this residue and the regulations governing its utilisation or disposal.

For example, depending on the standards in force in the countries where MWT plants are built, the slag may in certain cases be recycled, particularly in public works, with or without pre-treatment. In other cases, it is regarded as industrial waste. In general, the minimum requirements set down by regulations stipulate that the slag be collected separately from the fly ash and the flue-gas treatment residues.

Here are some examples of treatment and/or recycling:
- immediate use in public works as hardcore material without special treatment, subject to observance of certain precautions aimed at protecting groundwater tables;
- extraction of iron followed by recycling as hardcore material in road construction, subject to the conditions mentioned above. Such recycling likewise depends on a thorough knowledge of the characteristics of the slag and on periodic inspection (to determine the composition, unburnt matter, leaching etc.);
- extraction of iron followed by storage in an intermediate dump where it can mature for several months before being recycled as hardcore or taken away for non-controlled dumping;
- screening and coarse extraction of iron, leaching (to reduce the chloride and sulphate content), maturing in an intermediate dump, screening and fine extraction of iron followed by use as hardcore, or dumping;
- no recycling possible. The slag is regarded as hazardous waste and must be stored in controlled dumps on a well-sealed site and protected from rain and surface water.

4.6.2 Fly ash and dusts

The fly ash and dusts carried by the flue gases and captured by the dedusting filter (electrostatic or bag filter) contain heavy metals soluble in water, namely lead, zinc, copper and cadmium. For this reason, these ashes and dusts are rightly considered in many countries as toxic industrial wastes.

Various relatively simple processes exist for turning these ashes and dusts into inert residues, for example:

Inertisation in cement or bitumen
In these processes, the residues are mixed with cement and additives or with bitumen, a chemically inert material, and then cast into blocks. Once the mixture has solidified these blocks are dumped.

Scrubbing with acidic water

In this process, acidic water is drawn off from the flue-gas treatment system. After scrubbing the ashes and dusts, the materials in suspension are separated in a filter press or band filter. The scrubbing water, containing heavy metals and salts, is discharged into the MWT plant's effluent cleaning system.

The 3-R system

This system was designed at the nuclear research centre in Karlsruhe, Germany. The fly ash is scrubbed with acidic water as described above. The insoluble fraction of the ash is introduced into the furnace where it bonds with the slag. The scrubbing water is treated in an effluent cleaning station, and the filter cakes containing a high concentration of heavy metals are conveyed to a recycling station.

Vitrification

The dust and ash and also the solid residues extracted from the flue-gas scrubbing water are heated to a high temperature in an electric furnace until they reach vitrification temperature. The inert, vitrified product can be used as hardcore material. The gases, laden principally with gaseous heavy metals, are led to the flue-gas treatment system.

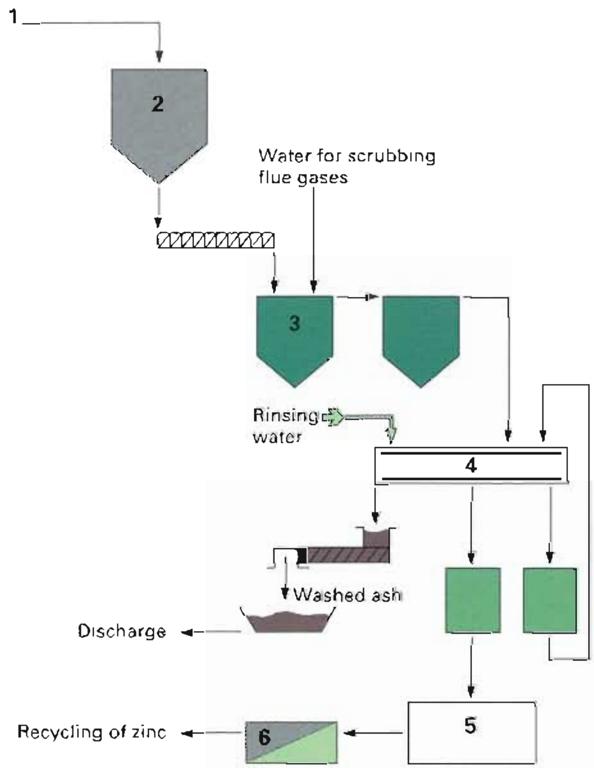
4.6.3 Solid residues extracted from the flue-gas scrubbing water

The sludges produced by the flue-gas scrubbing water treatment system contain mainly gypsum and heavy metal compounds insoluble in water (hydroxides or sulphides).

The sludges resulting from the scrubbing of the dusts and fly ash contain silicates (SiO_2), calcium compounds ($CaSO_4$) and aluminium oxide (Al_2O_3).

They can be treated by a relatively simple process enabling these toxic residues to be dumped without posing any threat to the environment. This involves adding cement and various reagents to the sludges and mixing thoroughly.

Once the mixture has solidified, the material can be dumped in the form of large concrete blocks.



Treatment of solid residues produced by scrubbing flue gases with acidic water

1 Fly ash from the boiler and from the filter
2 Silo
3 Extraction reactor
4 Band filter
5 Treatment of scrubbing water
6 Filter press/dryer

5 Description of a municipal waste treatment plant

The municipal waste treatment plant described below follows a modern design based on proven conventional technology. Despite greater international harmonisation of rules governing waste treatment and environmental protection since 1990, it is still impossible today to describe an international "standard" model for a municipal waste treatment plant.

These installations are built and operated according to the standards applicable to plants for incineration of domestic refuse and commercial and industrial waste similar to domestic refuse, and to installations for incinerating uncontaminated waste from hospitals and similar establishments.

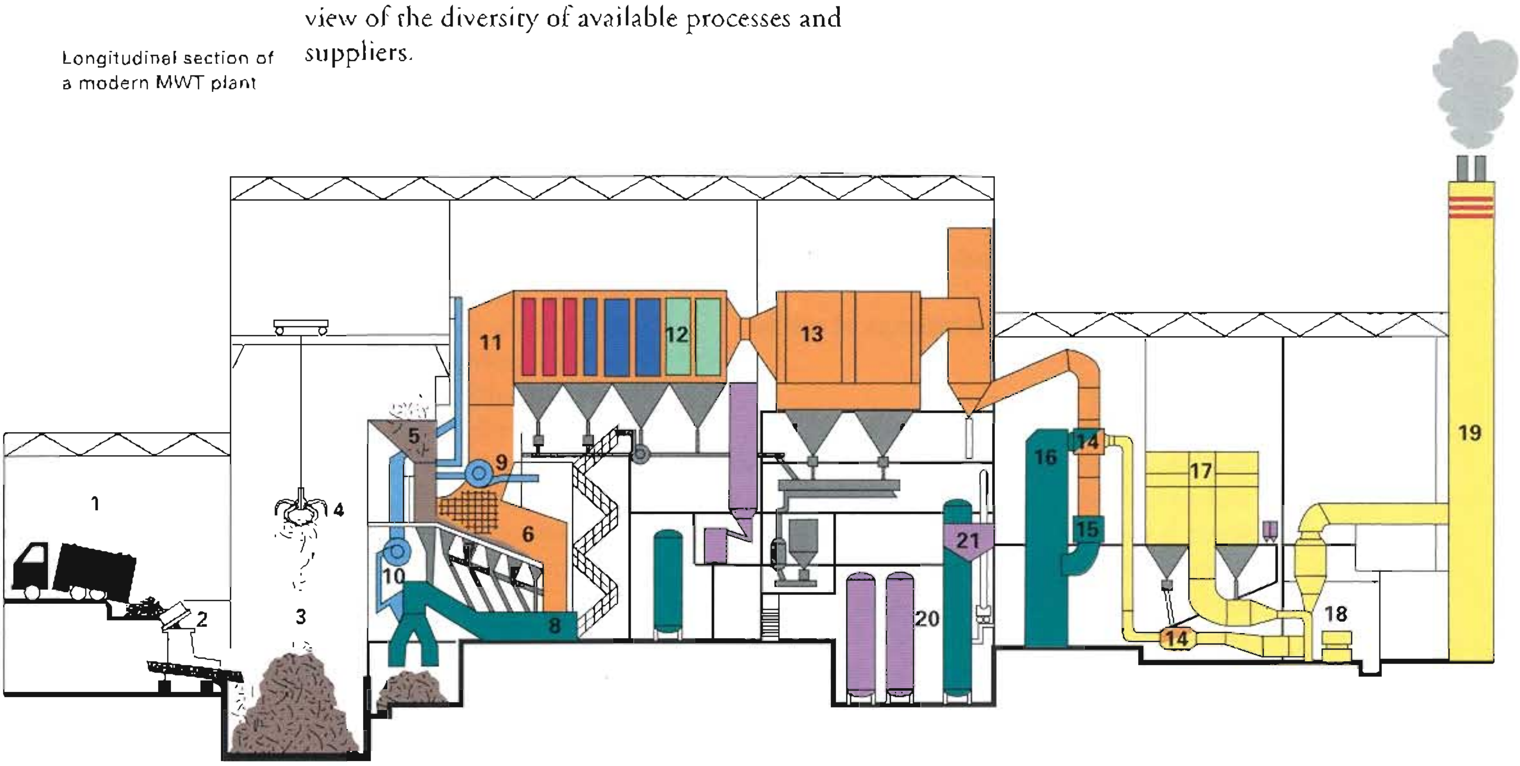
In the following, we describe only the principal elements of the MWT plant. A detailed description of all the equipment is hardly feasible in view of the diversity of available processes and suppliers.

5.1 Structure of a conventional MWT plant

The main sections of a conventional plant for the treatment and incineration of municipal waste are as follows:

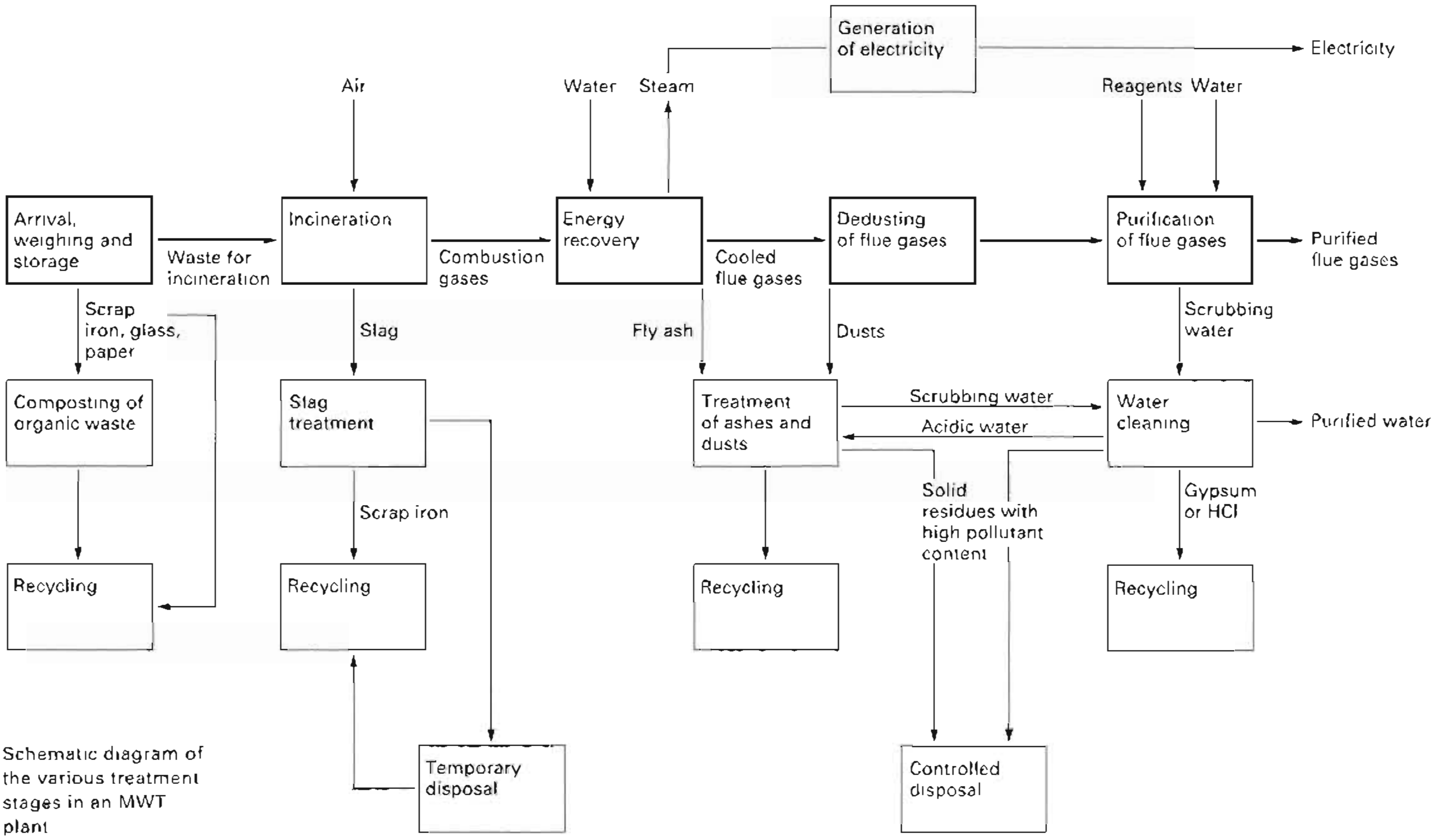
- entrance zone with weight scale and refuse receiving area
- shed for tipping and storing waste to be incinerated
- incineration furnace and auxiliary equipment
- thermal equipment for heat recovery and recycling
- flue-gas treatment and evacuation system
- residue treatment installations
- electrical installations and control system
- auxiliary installations
- buildings

Longitudinal section of a modern MWT plant



1 Unloading bay
2 Shredder for bulky waste
3 Waste bunker
4 Overhead travelling crane with grapple
5 Charging hopper
6 Combustion chamber
7 Hoppers below grate
8 Slag discharger
9 Start-up burner
10 Combustion air fan
11 Post-combustion chamber
12 Heat recovery boiler
13 Dedusting filter
14 Heat exchangers
15 Water injection (quench)
16 Flue-gas scrubbing tower
17 Bag filter
18 Extraction fan
19 Stack
20 Vats containing chemical reagents
21 Water purification systems

The concept of rubbish varies greatly, and in particular depends on a country's level of economic development.



Schematic diagram of the various treatment stages in an MWT plant

5.2 Description of principal equipment

5.2.1 Registration and storage of waste

Weighbridge

Domestic refuse and other similar waste is brought to the plant by refuse collection lorries and by individuals. Before being unloaded, the waste is weighed on a weighbridge situated at the entrance to the plant. Weighing and registration are fully automatic thanks to a tag attached to the municipal collection lorries. A registration and weighing ticket is issued for each lorry-load.

Unloading and storage of waste

Following registration, individuals can unload their waste in the refuse receiving area which has suitable pits, bins and storage areas. The sorted waste is generally made up of organic waste, bulky metal objects, paper, cardboard, plastic materials, glass and batteries.

After registration, the collection lorries are directed to the unloading bay, where they empty their load into the waste bunker. The volume of the bunker is normally designed to store sufficient waste to enable the plant to run seven days per week at nominal load. This is why refuse storage bunkers need to be so large. They are able to accept excess quantities of waste even on long weekends or during breakdowns or inspections of the installations.

There are normally one or two additional bays not accessible to the collection lorries reserved for stacking of waste. Stacking involves transferring the waste using an overhead travelling crane mounted above the unloading platform to where the bunker extends into a shell but has no discharge doors.

The waste is mixed together by the grapple attached to the overhead travelling crane before being dropped into the incinerator's feed hopper.

To avoid dust and unpleasant odours escaping outside, a slight vacuum is maintained in the refuse storage pit by extracting the combustion air required for the furnace.

After being tipped into the bunker, the waste is picked up by the grapple of the overhead travelling crane, which usually operates semi-automatically.

An overhead travelling crane normally comprises two transverse beams, a trolley which runs along these beams and a grab bucket called the grapple. The operator loads the grapple and carries out the stacking operations manually. The furnace feed hoppers are filled automatically as soon as the grapple has picked up its load. MWT plants are equipped with at least two overhead travelling cranes. The second emergency crane remains idle in the station situated at the end of the bunker.

Large or bulky items of waste (wooden doors, bedsteads, mattresses etc.) are tipped into a special hopper situated in the tipping area. So as not to disturb the loading and feeding of waste to the furnace, these bulky items are first shredded with a shear positioned in such a way that it can be fed by the overhead travelling crane, and the shredded waste is then fed by gravity down the chute into the main pit.

5.2.2 Incineration furnace

The incineration furnace basically comprises a waste feed system, a combustion grate, a combustion chamber, a combustion air system, a slag discharger system and hydraulic control systems.

Furnace feed

The waste materials automatically tipped into the furnace charging hopper fall by gravity into a feed chute. This chute must be permanently filled with waste to seal off the furnace combustion chamber from the refuse pit.

Feeding device

The furnace is fed by a feeding device with alternating and controlled movement cycles, running on a horizontal table situated at the bottom of the feed chute. It works continuously, feeding waste without manual intervention thanks to the combustion power control system. The cycle time, length of travel and speed of the hydraulically activated ram feeder can be controlled depending on the quality of the fuel (H_U of the waste) and the desired thermal value (steam production).

Combustion grate (Von Roll reciprocating grate)

The mechanical grate is the central component of the furnace. Each grate is made up of alternating fixed and moving bars. Hydraulic jacks provide alternating travelling motion at low amplitude to the bars causing the waste to progress along the grate.

Before falling as char into the slag shaft situated at the end of the grate, the waste undergoes successive phases of drying (by contact with the combustion gases, the hot air injected under the grate and by the heat radiated from the combustion chamber), degassing and gasification (decomposition into volatile and mostly combustible materials), and combustion.


The interior of the combustion chamber of a grate furnace prior to cladding with refractory brickwork. You can see the walls of the boiler and the secondary air injection nozzles

To ensure complete combustion of the waste and of the gas products in all phases of the incineration process, the following basic parameters must be respected:

- the waste must remain in the furnace for a sufficient period of time (approximately 45 minutes);
- the combustion temperature must be sufficiently high, i.e. between 850°C and 1,050°C;
- turbulence must be created in the post-combustion zone by the addition of secondary air to ensure complete combustion of unburnt materials in the gases.

Since the temperature in the combustion chamber is maintained at around 900°C, the grate blocks made of refractory cast iron have an operating temperature in the region of 200°C. To avoid high-temperature corrosion damage, these blocks are cooled from the outside by the combustion air and are protected from heat radiation in the combustion chamber by the layer of waste on the grate (the refuse bed).

Hoppers under the grate

Chambers shaped like inverted pyramids are situated under the combustion grate. These recover the ashes and other products that fall through the gaps between the grate blocks. Also, it is through these hoppers or chambers that primary combustion air is injected under the grate.

Hydraulic plant

A hydraulic plant supplies the jacks actuating the ram that feeds the furnace and the mobile bars of the combustion grate. Even in an incineration plant without automatic combustion control, it is possible to automate the speed of the alternating movement of the grate and of the ram feeder by defining simple parameters such as combustion temperature and the thermal load of the furnace.

Combustion chamber

As its name suggests, the combustion chamber is the part of the furnace where combustion takes place. Combustion starts in the lower part above the grate and reaches a height defined as the boiler intake. The combustion chamber is exposed to high temperatures, chemical corrosion and abrasion (caused by the slag in its lower part and the flue gases laden with solid particles above the hearth). Therefore it must be lined with refractory materials resistant to high temperatures and abrasion. The lower part is normally lined with refractory bricks and the upper part sprayed with refractory concrete.

Slag discharger

Once combustion is completed, the incandescent slag runs off the end of the grate via the slag shaft into a metal channel filled with water and equipped with a sloping conveyer belt. This belt moves slowly to enable the slag to drain off. This channel, called the slag removal channel, has the following functions:

- cooling the slag and removing it to the slag pit;
- sealing off the combustion chamber;
- serving as a safety valve in case of excess pressure in the combustion chamber.

Note on the sealing of the furnace: The furnace is sealed off by the hoppers under the grates and the slag shaft which extend into the water of the slag remover, thereby creating a hydraulic seal and enabling the furnace to be placed under a vacuum by the flue-gas extractor fan. The feed hopper is sealed by the plug of waste.

Start-up and booster burners

In Europe, every new incineration plant is equipped with booster burners. To comply with current European standards, the burners must be activated during the start-up and shut-down phases so as to ensure a minimum temperature of 850°C when waste is present in the combustion chamber. Furthermore, these burners automatically ignite when the temperature falls below 850°C during normal operation.

The combustion of waste at temperatures in the region of 900°C means the equipment is exposed to chemical attack and enormous thermal stress.

Combustion air system
The combustion air system comprises two subsystems:
Primary air system: provides both combustion air for incineration on the grate and cooling air for the grate blocks (and for the side walls of the furnace next to the grate, if necessary).
Secondary air system: ensures complete combustion of the combustion gases.

Primary air system
The primary air is extracted from the refuse storage bunker to prevent unpleasant odours escaping and causing a nuisance to the surrounding neighbourhood. The air is then blown into the furnace via the grate blocks. To facilitate combustion of waste with a low H_u, the combustion air can be preheated in a steam air reheater before being injected into the furnace.

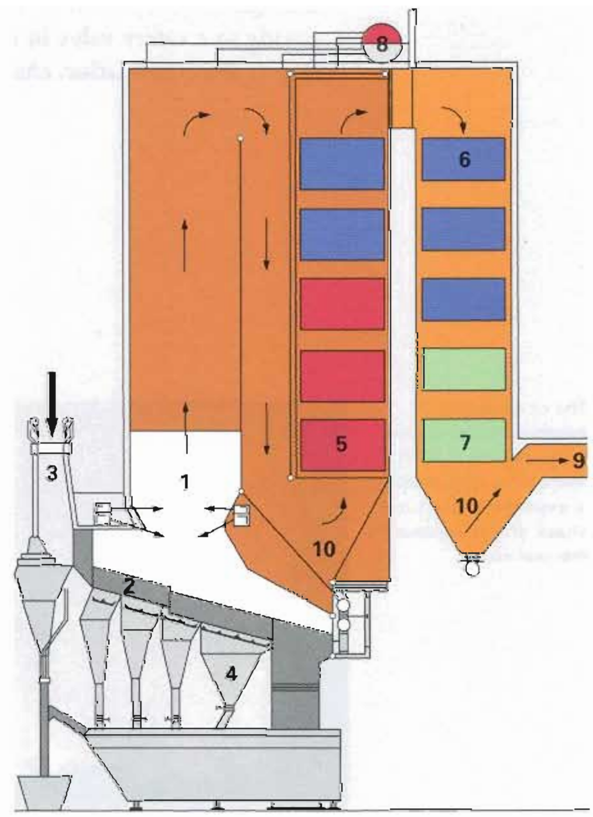
To prevent molten slag (at 900°C) adhering to the side walls of the combustion chamber and so as not to disturb the advance of refuse on the grate, part of the combustion air can be injected via perforated refractory panels fitted on the side walls of the furnace.

Secondary air system
The secondary air is injected at high velocity above the refuse bed in the narrow section of the hearth. Its purpose is to ensure complete combustion of the volatile components escaping from the furnace.

Both the air system and the hearth must be designed in a way that ensures intense agitation directly above the refuse bed, resulting in rapid decomposition of those gases which have not been completely burnt, particularly carbon monoxide (CO).

This prevents any reduced atmosphere above the zone protected by the refractory concrete, thereby avoiding the well-known problems of boiler corrosion in the furnace.

The injection nozzles are arranged at the front and rear of the furnace. They are dimensioned to ensure air penetration to the necessary depth and an optimum mixture of combustion gases.



Longitudinal cross-section of a grate incineration furnace/boiler

Incineration furnace:
1 Combustion chamber
2 Combustion grate
3 Feed chute
4 Hoppers under grate

Three-pass vertical boiler
5 Superheaters
6 Evaporators
7 Economiser
8 Steam drum
9 Flue-gas output to filter
10 Ash hoppers

5.2.3 Boiler and thermal equipment

A steam generator situated above the furnace recovers the thermal energy contained in the combustion gases, cooling them to around 200°C.

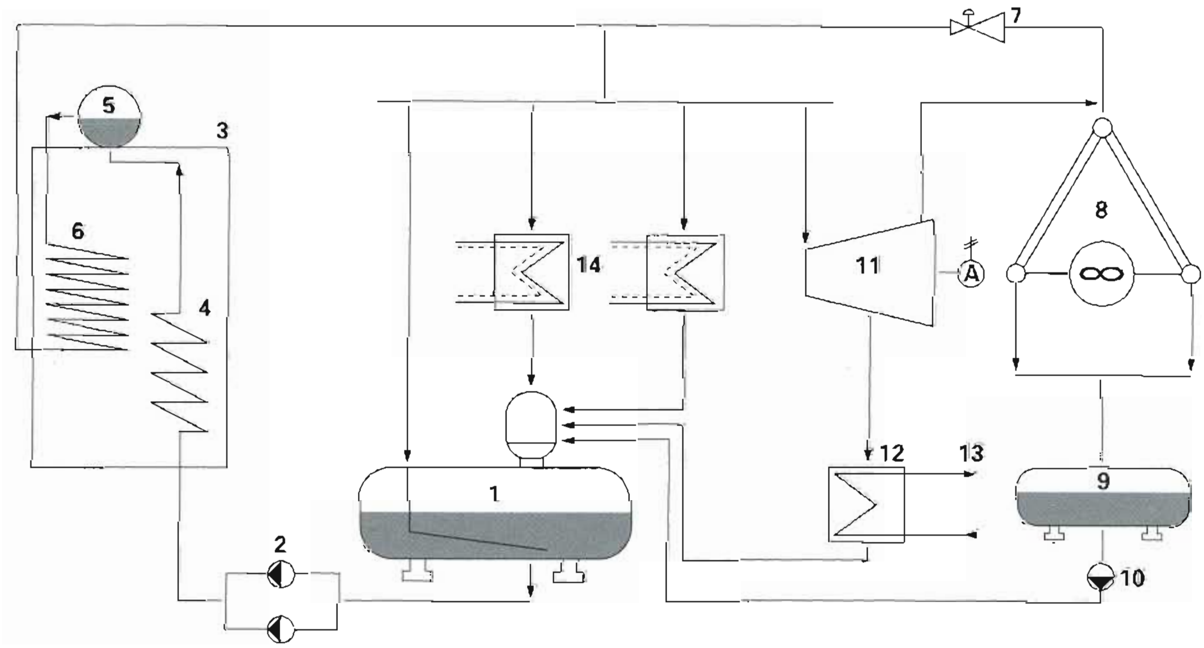
This steam generator is normally designed as a natural circulation boiler, either of the vertical three-pass type or of the horizontal two-pass type. Depending on size, the two passes of the boiler may be equipped with an economiser, evaporator bank of tubes and superheaters. The main body of the boiler is a self-supporting rigid tubular assembly which rests on a frame. The walls of the boiler are made up of welded gilled pipes that form a membrane, i.e. a totally sealed channel. The evaporating system, using natural circulation, has the steam drum situated above this. This is where water/steam separation takes place via the bank of tubes in the main body, the evaporators and the connecting pipes.

Before being introduced into the steam drum by the feed pumps, the demineralised water from the feed tank passes through the economiser, whose temperature is raised to a level slightly below evaporation point. In the economiser, the water circulates in the opposite direction to the flue gases.

The steam is led from the steam drum to the superheaters in order to raise it to its operating temperature. The pressure of the steam is held constant by the air-cooled condenser.

Schematic diagram of the thermal equipment in an MWT plant

1 Feedwater tank
2 Boiler feed pumps
3 Boiler
4 Economiser
5 Steam drum
6 Superheater
7 Tipper
8 Air-cooled condenser
9 Condensate vessel
10 Condensate pump
11 Turbogenerator
12 Heat exchanger
13 Hot water circuit
14 Primary air reheaters



The risks of corrosion are in principle eliminated by a suitable choice of materials and by the layout and geometry of the boiler components. These have to be optimised on the flue-gas side by performing tests on scale models in the laboratory.

In horizontal-pass boilers, the convection exchange surfaces are kept clear by a mechanical device which strikes the side walls. In the case of vertical pass boilers, the surfaces are swept free by compressed air or steam.

The steam produced is normally supplied to a turbogenerator to produce electricity. Depending on the needs and configuration of the plant, condensation turbines or back-pressure turbines may be used if part of the energy contained in the steam is to be utilised for hot water production or for an industrial process.

5.2.4 Flue-gas treatment system

Dust removal from combustion gases

After being cooled in the boiler, the combustion gases pass through a filter in which at least 99% of the fly ash is removed. Either bag filters or electrostatic precipitators can be used.

Electrostatic precipitators

The flue gases entering the electrostatic precipitator pass through a powerful, high-voltage electric field in which the particles of dust are electrostatically charged and are deposited on precipitation plates and then fall into dust hoppers. The plates are periodically struck in order to remove adhering dust. Electrostatic precipitators normally comprise two or three electric fields.

Electrostatic precipitators are highly efficient at separating dusts, removing more than 99.9%, but they are not able to capture gaseous pollutants such as hydrochloric acid (HCl), hydrogen fluoride (HF), sulphur oxides (SO_2), nitrogen oxides (NOx) and aerosols. These substances have to be removed in the flue-gas scrubbing installation situated downstream of the filter.

Flue-gas scrubbing plant

(Von Roll system, see also page 48)

The gas scrubbing system comprises a quench for pre-treatment of gases (cooling by injection of water) and a scrubbing tower which has between 2 and 5 treatment stages in which the following can be separated:

- gaseous pollutants such as HCl, HF, SO_2
- ultra-fine dusts and heavy metals in the form of aerosols.

Depending on the anti-pollution standards in force in the country where the MWT plant is built, the installation may also include a denitrification system (SCR or SNCR) and a bag or activated carbon filter to improve the overall flue-gas treatment efficiency, and to intercept dioxins and furans.

Flue-gas scrubbing towers in an MWT plant with three treatment lines

To prevent a plume of water vapour forming at the output of the stack, the purified flue gases may be reheated in a heat exchanger.

Pre-treatment of flue gases (quench):

Once the dusts have been removed, the combustion gases pass through a quench where they are cooled by the injection of water until they reach their saturation point. In this first treatment stage, pollutants such as HCl and HF are mostly absorbed by the scrubbing water.

Multi-stage flue-gas scrubbing tower:

The first stage of the scrubber actually constitutes the water reservoir of the quench circuit.

The second stage, comprising a tower packing layer, has several functions: conditioning of gases in preparation for the following stage, thanks to the very large contact surface area of the tower packing (polyethylene brushes, see cover page), promoting an optimum exchange of substances; the absorption of pollutants such as HCl and HF and, where necessary, neutralisation of SO_2 by the injection of caustic soda (NaOH). Aerosols, certain heavy metals and ultra-fine dusts are separated in the final zone of the scrubbing tower which is equipped with a ring-jet (Venturi) system.

The stages of the scrubbers are separated by demisters which prevent droplets of water being carried along by the flue gases.

This cascade system of flue-gas scrubbing produces a concentration of pollutants in the scrubbing water of the first stage of the tower. Part of this water is drawn off to be treated in an effluent treatment plant.

Treatment of scrubbing water

The main phases of treatment are neutralisation, flocculation, precipitation and decantation. Heavy metals may be removed from the water mechanically with a filter press or a band filter. The filter cakes are regarded as toxic waste and the treated water may be discharged into the sewerage system after adjustment of the pH and the temperature.

6 Waste treatment costs

6.1 Environmental technology

According to a study by the EC, the market with the potential for the highest annual growth rates between now and the year 2000 is the environmental technology sector. This sector consists of about 20,000 companies employing over 600,000 people across Europe, and its annual growth rate of almost 5% ranks it eighth in the economic sectors of the EC.

Germany is by far the biggest market for environmental products and environmental protection services. Of the ECU 47 billion invested in the EC in 1990, 36% was invested in Germany. It should be noted that a substantial proportion of this investment was concentrated in the water industry, waste water treatment and solid waste treatment.

Whereas in the private sector the lion's share of investment is spent on environmental protection measures to improve the quality of emissions into the atmosphere, the public sector tends to invest mainly in water treatment technology and plants.

There is a large scope for growth in the EU member states, who, to date, have tended to ignore environmental protection. In certain industries there is likely to be strong growth in the areas of waste treatment, soil decontamination and ecological services (engineering, environmental consultancy).

Turnover and growth rates in environmental technology sectors

Country	Turnover in ECU bn		Annual growth rate
	1990	2000	in %
Germany	17.0	23.0	4.0
France	10.0	15.0	5.5
UK	7.0	11.0	6.3
Italy	5.0	7.0	6.0
Netherlands	2.7	3.7	4.1
Spain	1.8	3.0	7.4
Belgium	1.4	2.3	6.4
Denmark	1.0	1.2	2.2
Portugal	0.4	0.7	8.3
Ireland	0.3	0.5	6.5
Greece	0.3	0.5	7.4
EU	46.9	68.6	4.9
USA	78.0	113.0	5.0
World	200.0	300.0	5.5

Source: European Commission /OECD

The problem of waste disposal cannot be solved simply by waste incineration. Incineration residues (slag) must also be treated properly before being either recycled or disposed of.

Up until the end of the eighties, most investments in the field of environmental protection were made in the public sector, and were governed by standards and directives. Over time the private sector has also woken up to the fact that it is in companies' own interests to keep up with and ahead of trends in environmental regulations. Furthermore, industrial conglomerates have increasingly realised that projecting a positive environmental image can considerably enhance a company's growth prospects. One only needs to look at the big increase recently in the number of cleaning products advertised as phosphate-free and biodegradable.

This new marketing angle has obliged companies to invest substantial sums in research and development. In big multinationals, R&D can account for up to 8% of annual turnover. As a result, companies have perfected new "green" products or environmental technologies which have excellent growth potential.

One of the obvious conclusions to draw from this phenomenon is that the escalating importance of R&D makes it more difficult for smaller companies to compete in new markets. Attracted by the prizes, many smaller companies and engineering offices have become involved in the development and design of new waste treatment or flue-gas purification processes. However, they have not managed to commercialise their products because of a lack of financial backing, such as the funds needed to construct a pilot installation.

6.2 Waste incineration costs

Adapting existing MWT plants to bring them into line with new environmental protection legislation – especially air emission controls – requires massive investment, mainly for constructing flue-gas treatment systems.

The investment needed to build an MWT plant far exceeds the income earned from the heat recovered from the waste. Variability is a key element in the waste treatment sector. Investment basically depends on the following factors:

- the requirements specified in the environmental regulations of the country in question. The development of standards has a direct impact on the technical complexity of installations;
- the required degree of materials separation. If the aim is to obtain very small quantities of end-residues and a maximum amount of recyclable materials, the investment will be substantially higher.
- the desired level of operational convenience and reliability. The final cost will be pumped up significantly if the system includes a lot of redundancy and sophisticated operating and control mechanisms;
- the need to ensure that the plant blends in aesthetically with its physical setting. Apart from the architectural design, care must be taken to prevent excessive noise and bad smells.

Given the current state of available technologies and the regulations that must be complied with, the average investment required is normally in the region of ECU 150 m (excluding the price of the land) for constructing a new MWT plant capable of processing 100,000 tonnes of waste a year. A plant with this sort of capacity can serve a region of about 200,000 people.

For technical reasons, building one large MWT plant is less expensive than constructing several smaller ones. In sparsely populated regions municipal and rural authorities often have to coordinate their waste treatment activities. In Europe the current trend is no longer to construct one MWT plant in each city, but to build regional centres capable of processing up to 400,000 tonnes of waste a year.

The total costs for running and maintaining such a plant can be as high as ECU 150 per tonne of treated waste.

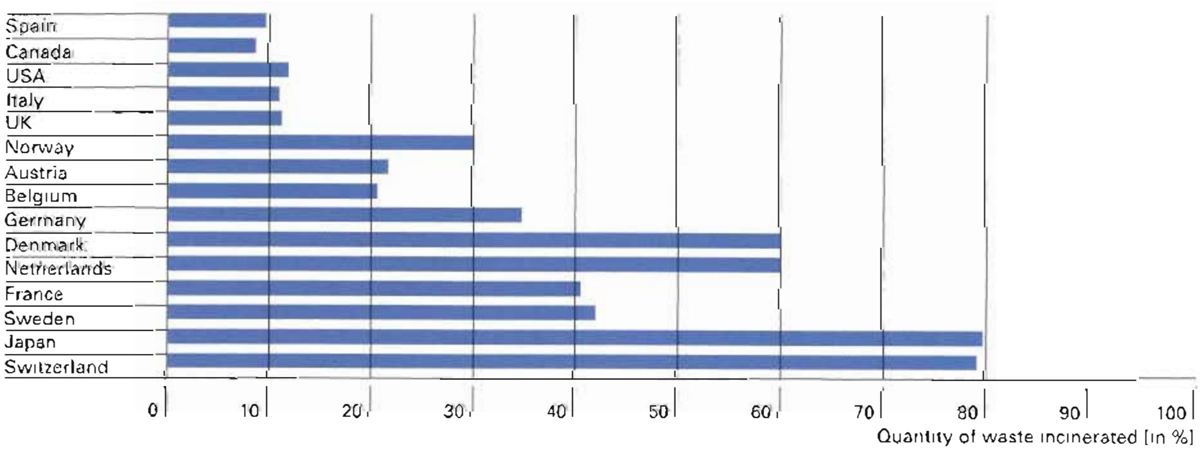
Internationally, there is a trend for countries with limited space for landfills to resort increasingly to waste incineration. Whereas 20% of household waste is incinerated on average across the EU, this percentage is more than 70% in Switzerland and Japan.

Some EU member states have only recently set maximum emission limits for MWT plants. Of the 535 waste treatment plants operating in Europe, only 15% or so are fitted with high-performance flue-gas treatment systems. Most of them only have one dust filter system, and almost 20% of these plants have no purifying system. The need to modernise the MWT plants by fitting flue-gas treatment technology requires investments totalling several billion ECUs.

Approximate breakdown of main items of total investments (excluding land) required for the construction of an MWT plant

Item	(% of total cost)
Civil engineering and buildings	10 – 25
Boiler furnace and thermal systems	30 – 40
Flue-gas purification	20 – 40
Treatment of residues	10 – 25
Electrical, control and operating systems	10 – 20

Percentage of municipal waste incinerated in each country



7 Dangers and typical damage

For a long time, waste incineration plants were regarded as a source of pollution since they consisted of little more than a furnace and a chimney stack. Nowaday, however, modern MWT plants are well accepted by the population in most countries.

For this to happen, the makers have had to invest considerable sums in research into new processes and new products able to satisfy ever more stringent pollution controls.

The use of new technologies involving many disciplines such as chemistry, thermodynamics and materials science has steadily increased the risk from the insurers' point of view.

MWT plant in La Rochelle, France. During the intermediate erection phase, installations are more exposed to damage by storms and wind.

The interior of a post-combustion chamber of a rotary furnace for incinerating special wastes. Settling claims relating to the refractory brickwork often presents problems for companies offering engineering insurance.

7.1 Dangers in the construction, erection and operating phases

Principal dangers during construction and erection

- Problems relating to transport and accidents during unloading of bulky loads on the site.
- High concentration of inflammable substances on the site, particularly bearing in mind that fire-fighting facilities are often inadequate or even non-existent.
- Insufficient measures to prevent corrosion and to protect materials stored on the site and in temporary storage areas from the effects of nature.
- Natural hazards, particularly storms, during the intermediate phase of erecting the structure and reactors.

Principal dangers during commissioning and operation

- Lack of water in the boiler due to a leak, human error or a fault in the control system.
- Explosion in the boiler.
- Fire in the flue-gas treatment system with consequent damage to the rest of the installation caused by acidic flue gases.
- Fire in the refuse storage pit and hopper, in the cable ducts, the control room and the transformers.
- Rupture of the pipes carrying steam and other acidic fluids capable of causing physical injury.
- Escape of inflammable substances in liquid or gas form and of combustible materials such as fuel oil, lubricating oil or ammonia from the denitrification installation.

MWT plant in South East Finistere, France: installing the boilers. Work on erecting the MWT equipment started well before the completion of the civil engineering and building works.

Stage pumps in a flue-gas scrubbing tower. Most of the materials used are inflammable plastic. This represents an aggravated fire risk

- Fire, danger to the environment and surrounding area caused by contaminated water used to extinguish the fire and by flue gases containing pollutants.
- Ice, e.g. in the boiler, the refractory lining or the water and steam pipes (particularly in the commissioning phase when the plant is not yet in continuous operation).
- Control and/or handling error due to personnel not being sufficiently familiar with the equipment.
- Interrupted operation for a period of months or even years following a fire or total loss of a major item of machinery.

Dangers associated with the technical maturity of the installations or their prototype nature

- Error of design or fabrication, material defect (risk is heightened by the rapid development of processes and technologies).
- Risk of errors in the erecting of new installations (the works normally have to be executed within a short time and in a limited space).
- The difficulty of establishing limits between the risk borne by the contractor and the insurable risks.

Miscellaneous dangers

- Deliberate damage, sabotage, strike, riot, popular movements (MWT plants are still not well accepted by the population in certain regions).
- Natural hazards (earthquakes, flood, storms etc.)
- Claims incurring civil liability: pollution, physical injury, damage to property and intangible damage.
- Major delay in final commissioning following a claim occurring at the end of the erection phase or during tests. If Advanced Loss of Profits cover is held, the damage may run to tens of millions of ECUs.

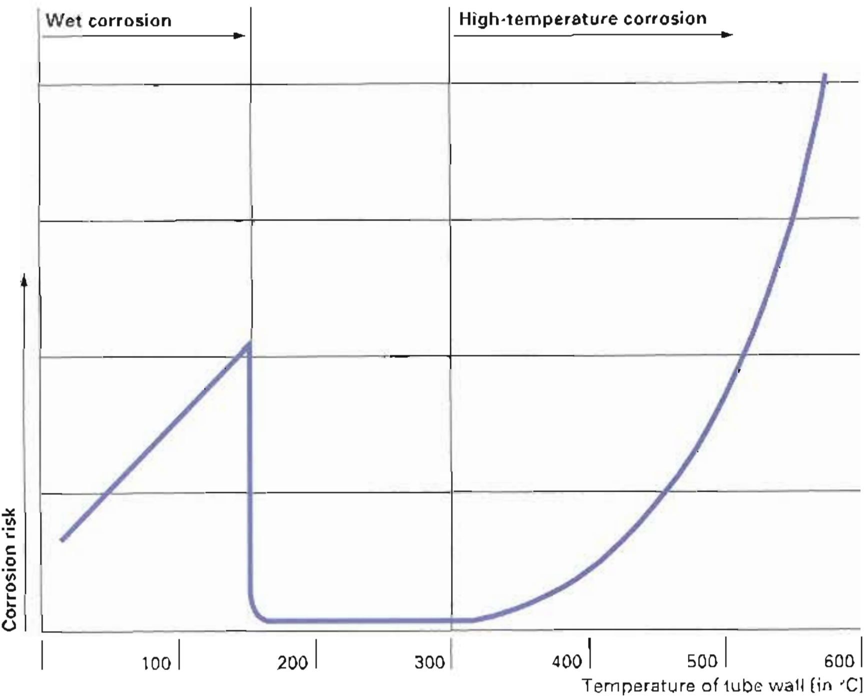
MWT plant in Frankfurt. the construction of industrial complexes in residential areas can give rise to all sorts of claims

7.2 Dangers associated with the process

7.2.1 Utilisation and handling of solid products

The treatment and utilisation of solids during the processes creates technical problems, because these materials may be abrasive and they may cause fouling and blocking when they absorb moisture. In the form of dust, they may cause explosions. In waste treatment plants, it is necessary to treat and handle a wide variety of solid materials such as ash, gypsum, slag, sludges, activated carbon, highly toxic filter cakes etc.

Corrosion curve for boiler tubes



7.2.2 Corrosive substances and environments

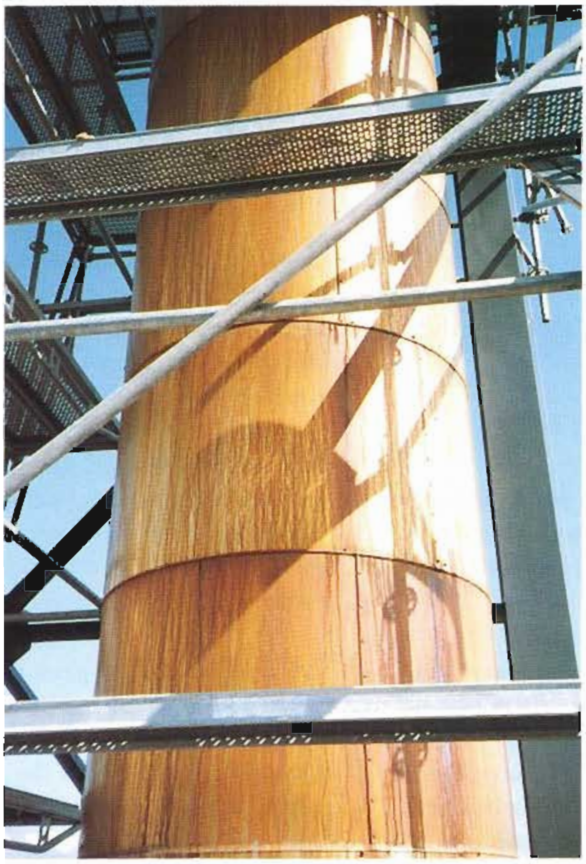
The flue gases produced by the burning of waste contain gaseous acidic substances such as HCl or SO_2. Consequently the flue gases become highly corrosive when their temperature reaches the condensation point of these acids at around 150°C. This means that all systems which come into contact with the flue gases from the boiler output onwards must either be maintained at a temperature above 150°C or they must be covered with anti-corrosive material. In the case of installations equipped with a wet scrubbing system, the acids are transferred from the flue gases to the scrubbing water. For this reason, the whole of the scrubbing water treatment system has to be made from plastic materials such as polyethylene or polypropylene.

Corrosion due to combustion gases in the furnace

In refuse incineration processes, it is not always easy to guarantee 100% combustion throughout the furnace. If the organic matter does not remain in the furnace for long enough, if the oxygen concentration is insufficient and if the necessary temperature cannot be attained, oxygen-deficient zones may occur, leading to the formation of carbon monoxide.

Experience shows that an oxygen-deficient atmosphere may have an adverse effect on the walls of the boiler tubes. The protective layer cannot form on the pipes (the layer protecting the pipes is attacked by combustion gases containing CO). Furthermore, in view of the fact that these gases contain corrosive matter, namely chlorides, sulphates and sulphides, corrosion is liable to occur and will very quickly destroy the steel pipes.

Acidic corrosion on the external walls of a chimney stack. This type of damage can arise when the flue-gas purification system is by-passed due to technical problems.



The incineration grates of waste treatment plants are exposed to high thermal and mechanical stresses. Waste increasingly contains plastic materials which impose additional stress, both thermal and chemical, on the incineration grate. A high content of waste made from synthetic materials causes local hot-spots within the layer of waste. As a result, the copper, lead and aluminium contained in certain wastes melt and enter the cooling channels where they solidify. The cooling air cannot circulate and the bars of the grate are damaged by the excessive heat. The layer of waste on the grate affects the service life of the combustion grate in two important ways: it protects it against radiation and resists the combustion air which cools the grate. Bad management of the installation creates holes in the refuse bed causing localised destruction of the bars of the grate due to high-temperature corrosion.

Corrosion due to combustion gases outside the furnace

Corrosive combustion gases coming from the furnace can, in the event of excess pressure on the flue-gas side, lead to severe corrosion damage if they escape through fissures or leaks. In the open air, these gases condense, cool and form acids which attack their environment.

The flue-gas ducts are kept under pressure. Therefore they must be welded to ensure they are impermeable to gases and to prevent any leaks during operation.

Corrosion in the flue-gas treatment system

The risks of corrosion vary depending on the methods used.

Flue-gas treatment system based on dry or semi-dry scrubbing:

In these installations, the causes of damage are linked to the use of lime.

Unwanted chemical reactions, problems with the dosing of the new and recycled lime and with the removal devices may lead to damage such as overheating of the filter bags, corrosion of the system or mechanical rupture of the screw conveyors and equipment for removing the used lime.

In the case of the dry process, for example, where treatment involves bringing the flue gases into contact with fine slaked lime ($Ca(HO)_2$), the reaction is as follows:

$$2\ HCl + Ca\ (OH)_2 > Ca\ Cl_2 + 2\ H_2O$$

In theory, one molecule of lime bonds with two molecules of hydrochloric acid to form one molecule of calcium chloride and of water.

The calcium chloride that is formed is very hygroscopic (present in the flue gases and thus produced by the reaction); it may therefore become deliquescent if the temperature of the flue gases falls below 90°C, leading to condensation. This phenomenon causes caking and difficulties with handling the recycled product, mainly when starting, stopping or slowing the installation.

Flue-gas treatment system based on wet scrubbing:

To avoid corrosion, the internal walls of the scrubbing tower and the other parts of the installation are coated with rubber or ebonite. This protective coating is often permeated by the diffusion of acidic water vapour. This can lead to the formation of pockets of acid behind the coating which in turn cause blistering and deep corrosion to the wall of the metal shell. The blistering is due to a variety of causes – possibly a manufacturing fault, a difference in temperature between the internal and external walls of the reactor, chemical influences or repairs carried out on site under adverse conditions.

Corrosion damage may also occur in the zone of the hot gases, where it is impossible to re-cover the internal walls with rubber, or in the zone of the purified flue gases, where anti-corrosion protection is sometimes absent.

As already mentioned, the gases produced on combustion of waste contain, besides water vapour, other corrosive substances capable of condensing, such as the acids HCl and SO_2, which pose a major corrosion problem.

The dewpoint of the gases is in the range of 150 to 340°C. Experience shows that for certain gas compositions, even at high temperatures, the dewpoint may be below the normal threshold, causing corrosion to develop.

7.2.3 High pressures

Under the standards in force in most industrialised countries, incineration plants are only granted planning consent on condition that the energy contained in the waste is recycled. For this reason, all new plants are equipped with recovery boilers which normally operate with superheated steam between 30 and 60 bar. Such plants are regarded as true cogeneration power stations, with total output sometimes as high as 300 MW.

7.2.4 Rotating machinery

Incineration plants contain a wide variety of rotating machinery. The largest and the most sensitive are undoubtedly the extractor fans and the steam turbine, though one should not forget the boiler feed pumps which, although small in size, are essential to the operation of the installation.

The extractor fans are normally situated downstream of the flue-gas treatment system, because this system should preferably be kept under a slight depression to avoid any accident or external corrosion in the event of a leak in a flue-gas channel or in the scrubbing tower. This means that the fans operate in a damp atmosphere, since the gases are saturated with water when they leave the scrubbing tower. For this reason, all parts which come into contact with the gases are ebonised. Dimensioning and designing these fans is a highly skilled task. Because of the ebonising, for example, the circumferential velocity of the impeller must be limited. The most frequent causes of accident are: corrosion of the carrier material and damage to the ebonite lining by foreign bodies carried by the flue gases, and destruction of shafts caused by heavy vibration (if the flue-gas treatment system is inefficient, dust deposits form on the fan and cause vibrations).

7.2.5 Fire and explosion

Experience shows that fires and explosions are today by far the commonest causes of damage in waste treatment plants. The main causes are as follows:

Fires in the refuse bunker

The storage of municipal waste in the pit poses a latent danger. The pit can be observed from the cabin of the overhead travelling crane, from where the operator can detect a fire starting as soon as smoke appears. But once a fire starts, dense smoke can spread in a matter of minutes, so that the only solution is to flood the bunker. Operators are reluctant to resort to this solution, since it results in the total shutdown of the plant for several days.

Fires in the charging hopper

Particularly in smaller installations, a fire can spread from the hearth to the furnace feed hopper. This happens mainly during the start-up phase, when the feed chute is half-empty, or during the first tests under load, if the feeding device is not working properly.

Fires in the flue-gas scrubbing system

In the past, many fires have occurred as a result of plastics, coatings, rubberised materials and other inflammable substances catching fire.

Special attention should be paid during erection and maintenance operations. Many flue-gas treatment systems which use wet scrubbing are internally coated with inflammable materials. One stage of the scrubbing tower contains tower packings made of plastic. These materials can easily catch fire from welding sparks, for example, or because of faulty site heating or lighting equipment.

Explosions caused by bulky waste

Fires and explosions can occur during the shredding of bulky waste items. Products contained in the waste such as gas cylinders, atomisers etc. can trigger explosions and fires in the bulky-waste shredding installation or the combustion chamber.

7.3 Typical damage

Possible damage to steam boiler tubes in municipal waste treatment plants.

The combustion gases contain large quantities of very fine solid particles. Therefore the tubes of preheaters, superheaters and evaporators arranged perpendicular to the flow of gases are subject to greater or lesser degrees of erosion (comparable to fine sand-blasting). The severity of such erosion mainly depends on the nature of the solid particles and the flow-rate of the combustion gases.

It is common for the tubes of a steam boiler in a waste treatment plant to become damaged. However, in the event of a leak, a large volume of water vapour can very rapidly spread within the boiler, seriously damaging the refractory compound inside the combustion chamber.

The greatest danger, in the event of a leak, is that the tubes of the combustion chamber will no longer be cooled. They can only be cooled with water under certain conditions, and since it takes between 15 and 30 minutes to extinguish the hearth, these tubes are exposed to very high thermal stress. In most cases, this overheating leads to severe deformation of the uncooled tubes which constitute the walls of the first pass of the boiler.

An accident in the boiler of an MWT plant serves to illustrate the mechanisms giving rise to this type of damage (corrosion of combustion chamber tubes by hot gases, erosion of evaporator tubes), and gives an idea of the disastrous consequences. These include not only the cost of replacing the damaged tubes, but also the costs of temporary storage, transport and incineration of municipal waste at another site while repairs are being carried out and the loss of income from sales of steam, hot water or electricity.

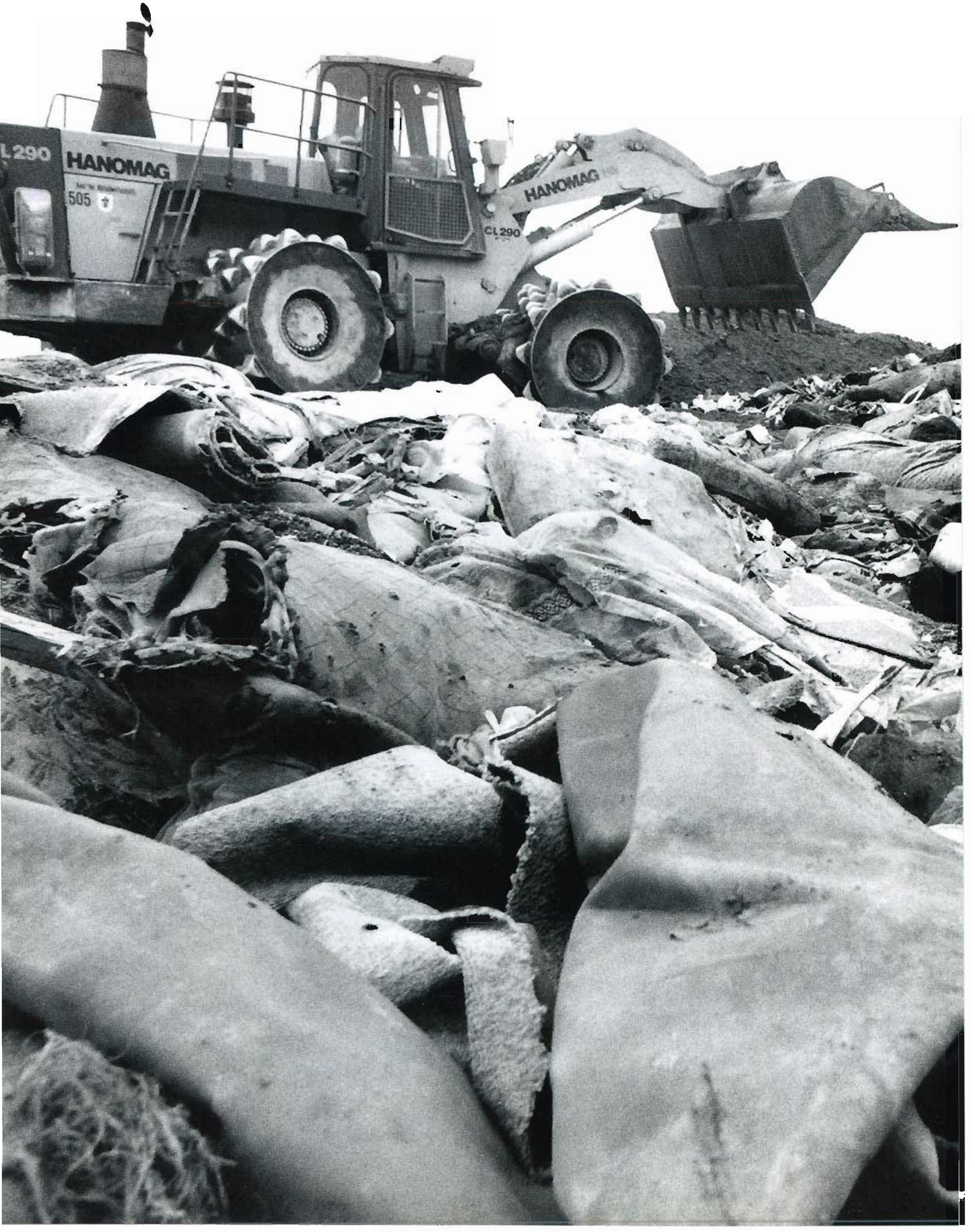
Damage to superheater tubes of a two-pass recovery boiler (Berne MWT plant)
The tubes whose walls are directly exposed to the combustion gases have been eroded to the point of perforation. From a metallurgical examination and an analysis of the deposits accumulating on these tubes, it appears that the wear was caused by acid corrosion (corrosion at the dewpoint of the acidic gases). The damage suffered by the tubes, i.e. the heavy wear on their walls, was very probably due to the combination of two types of attack: firstly, corrosion caused by sulphuric acid, and secondly erosion which wore down the surface layer of deposits formed by the corrosion, thereby re-exposing the tube wall to the corrosive agent.

Damaged refractory brickwork (shot concrete) on the walls of the combustion chamber, made up of boiler tubes.

The corrosion process described above can only take place if the temperature is below the dewpoint of the sulphuric acid. The dewpoint of gases containing water vapour and sulphuric acid is theoretically between 100°C (the dewpoint of water vapour) and around 340°C (dewpoint of pure sulphuric acid). The relatively large quantity of sulphates contained in the combustion gases suggests a high concentration of acids; in the present case we can estimate that the temperature of the tube wall was between 250 and 300°C. Such low temperatures are unusual in the latter part of the second pass.

In the combustion chamber, unprotected tubes undergo considerable oxidation and corrosion. The thickness of their walls diminishes by approximately 1 mm per month. This is why the entirety of the refractory compound must be checked regularly (every three to six months). This is an important and effective precaution against damage. On the other hand, it is not always easy to detect damaged areas of this compound, due to the accumulation of soot and incandescent slag. Any identified damage must be repaired immediately by specialists.

Corroded tubes from a boiler's superheaters. These tubes, which are not protected by refractory brickwork, are extremely exposed to corrosive and abrasive combustion gases.



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8 Engineering risks associated with the construction and operation of an MWT plant

The fact that environmentally responsible waste management and waste disposal has become a growing concern in recent years in industrialised nations undoubtedly has many positive aspects.

The previous chapters have shown that it is perfectly feasible to install systems that provide efficient waste management and disposal but which are also totally environmentally friendly. This implies, however, that all the parties concerned (public authorities, households, industry and commerce) are willing to make an active contribution.

In this context the insurance industry must, as always, strive to lend its support to society and, in particular, to its industrial clients that require cover for all types of risk. The main characteristics of MWT plant construction projects are their complexity, which makes interdisciplinary skills essential, and the high political and financial stakes. Companies face a series of problems if they are to fully satisfy the increasingly demanding requirements imposed by environmental laws.

Insurers, for their part, must be able to support their clients in the development of new products, offering them insurance conditions that are tailored exactly to their needs but without jeopardising insurability.

This chapter is designed to help underwriters analyse the factors affecting the construction or operation of an MWT plant. For a full description of engineering insurance, please refer to Swiss Re's specialised publications.

8.1 Main forms of engineering insurance

The most common engineering insurance used for waste treatment plants can be divided into two distinct categories:

Pre-operational cover
- Contractors' All Risks (CAR)
- Erection All Risks (EAR)
- Advanced Loss of Profits* (ALOP)
- Contractors' Plant & Equipment (PLEQ)

Operational cover
- Machinery Breakdown (MB)
- Machinery Loss of Profits (MLOP)
- Computer All Risks
- Boiler Explosion

8.2 Main project stages in the construction of an MWT plant

The construction project for an MWT plant usually takes the form of a turnkey contract between the client who commissions the project – seldom a private investor but more likely to be a group of several cantons, a syndicate of local authorities or a large municipality, etc. – and the project manager, who is usually a general contractor. The works involved in the construction, commissioning and operation of the plant carry diversified risks both in terms of their size and nature. In addition, many different professions and businesses are involved in the project, including:
- engineering consultants
- architects
- regulatory bodies
- different companies acting as a consortium
- a general contractor employing subcontractors, who in turn use their own subcontractors and suppliers.

Not many people are really aware of the vast amounts of waste we produce. To prevent us all being buried under our own rubbish, efficient waste management and waste disposal systems must be put in place.

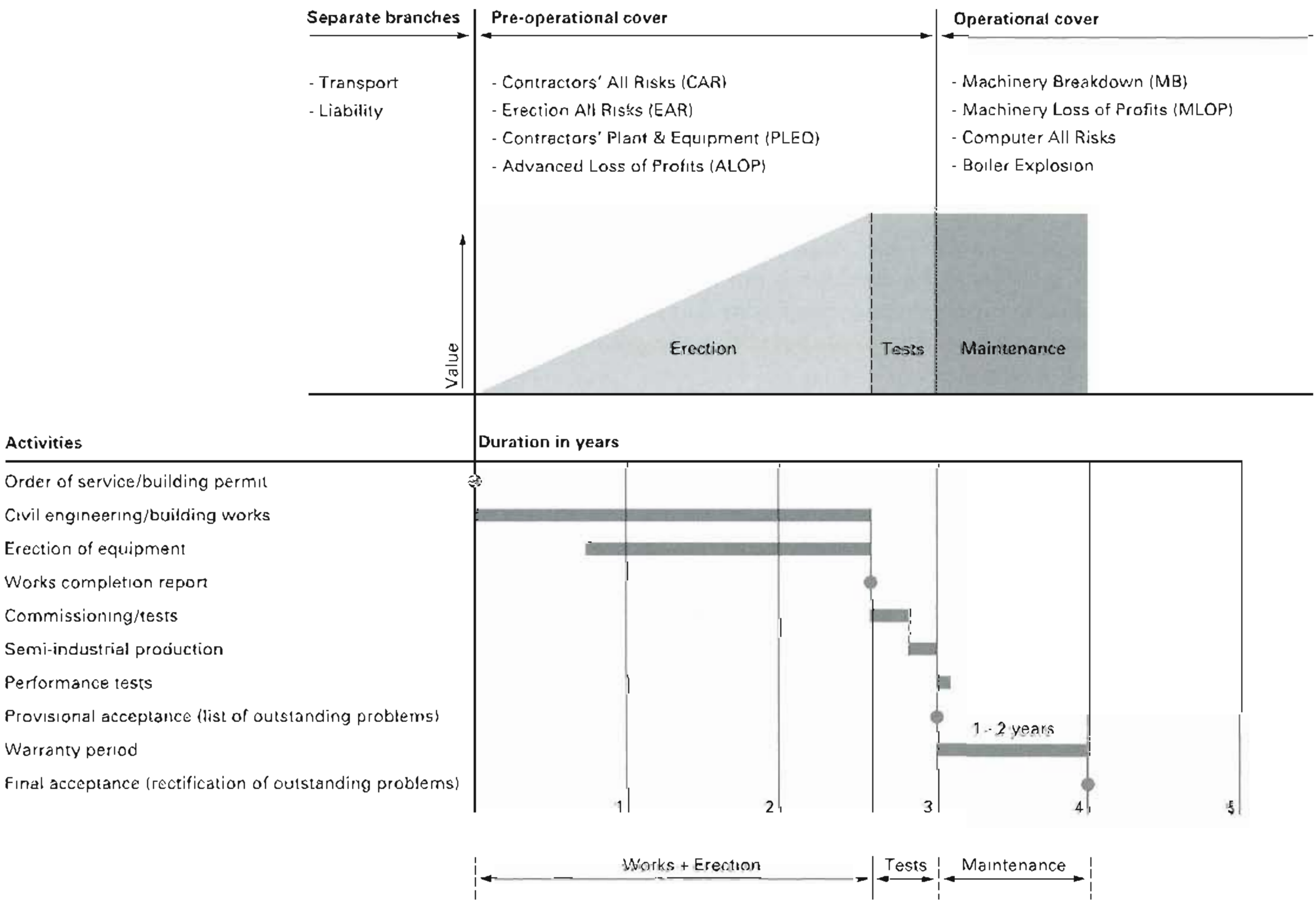
* only possible in conjunction with Contractors' All Risks or Erection All Risks cover.

It is essential that the insured parties (the client and the contractor) have insurance cover that is tailored to their needs during every phase of construction and operation. The technical risk often represents a large proportion of the whole risk, but other hazards, such as fire, natural phenomena and civil liability must be taken into account as well.

8.2.1 Civil engineering and building works

Excavation, laying out and foundation works
The initial laying out and excavation work on the building site can start as soon as the contractor receives written instructions. The site chosen for the new MWT plant is often on the outskirts of a town, in an industrial zone on poor terrain (old landfill, swampland, etc.). To this end the soil often has to be compacted or foundation piles need to be driven in or implanted with a vibrating compactor, to ensure even load distribution and a stable structure.

Engineering insurance during the construction and operation phases of an MWT plant



The refuse storage bunker, whose effective volume can be as much as $20,000m^3$, is usually constructed below ground level. Quite often there is a groundwater table. Although it is not that difficult to ensure that the bunker remains waterproof while the plant is under construction, the bunker could turn out to be a sensitive issue in the decennial guarantee.

Another point to bear in mind about the construction work is that more and more countries are now insisting that the site has a waterproof barrier to prevent pollution contaminating the soil, rivers and groundwater. For this reason, the drains for collecting rainwater, waste water and water used to extinguish fires must be fed into a retention basin based on the "Schweizerhalle" model.

An MWT plant generates a lot of traffic. In addition to the supply network inside the plant (roadways, parking, access ramp to the unloading shed, manoeuvring zone for trucks, etc.), access roads to the MWT plant also have to be constructed or upgraded.

Buildings

There are two general trends:

The first is to site MWT plants away from built-up areas. In this case the building has a simple design and is limited to a furnace/boilerhouse, a control room and administration and outbuildings (offices, meeting rooms, changing rooms, workshops, canteen, etc.). The flue-gas treatment system and residue treatment systems are not covered over. The whole construction is made of reinforced concrete and is no more than one or two storeys high. The rest is built as a steel structure clad with panels.

The second type of building is intended for MWT plants located near residential areas. Here the external design is completely different and its cost can amount to more than 25% of the cost for the entire plant. All the equipment is housed inside the building, which is a robust watertight structure made entirely of reinforced concrete so as to keep down noise pollution and odours.

Greater care is usually taken with the architectural design of the building, to ensure that it blends in with its surroundings. These constraints on the building design slow down construction, firstly because the building work takes longer and overlaps with the equipment erection phase, and secondly because it is sometimes difficult to install large components such as the boiler or other bulky machinery in the building.

In the event of a serious accident this design can also have unfortunate consequences because it complicates access to some equipment, making it more difficult to dismantle and reassemble. So repairs take longer, adding to the final cost of the loss. Another negative aspect, from the insurer's point of view, is the catastrophic impact that a fire can have inside a building, because pollutant and corrosive gases can cause serious damage to a large proportion of the installations.

The civil engineering and building works phase does not end until the client provisionally accepts the MWT plant. Although a substantial percentage of the works are complete by the time the erection stage starts, painting, metal work and external landscaping continue up to the end of the project.

8.2.2 Erection of equipment

As long as there are no exceptional problems with civil engineering and building works, a start can usually be made on erecting the equipment about 12 months after the construction site opens.

Work usually commences by erecting the steel structure of the furnace/boiler unit at ground floor level. Once assembled, the boiler and the furnace constitute a single element, which is also the heaviest and bulkiest piece of equipment in the whole plant (it can easily be 30 m high). The furnace/boiler and other vital components (reactors, filters, air condenser, etc.) are transported to the site in separate sections in special convoys. Any handling operations (unloading, hoisting, mounting) also require heavy lifting gear.

To cut down the surface area of the MWT plant, thereby reducing its cost, the flue-gas treatment system is not installed at ground level as a continuation of the incineration line, but on a raised platform within the building. This can pose a slightly aggravated risk in terms of Erection All Risks cover, because the reactors, filters and chimney stacks are more susceptible to storm damage while being erected.

Towards the end of the project, when all the finishing work is in progress (pipework, electrical wiring, heat insulation, metal gantries, paintwork, etc.), there may be several hundred workers on site. This undoubtedly poses an aggravated risk as far as liability is concerned, and physical injury is certainly not uncommon at this stage of the operations.

8.2.3 Commissioning the plant

The period between the completion of the erection phase and the client taking possession of the plant is very important for insurers of engineering risks. In the case of an Erection All Risks policy, capital exposure is at its greatest once the works have been completed. The consequences of a fire, for example, could be disastrous. Furthermore, it is during this period that the first tests under load are performed on the machinery, and it is obviously the time when most of the design and erection errors come to light, along with any material defects, etc. If Advanced Loss of Profits cover has been taken out, this is a critical phase in the project, because cover expires on the same date as the provisional acceptance of the plant.

Even experienced underwriters sometimes find it difficult to decipher the contractual documents and pinpoint the exact duration of the various operations that take place during this delicate period. We found it worthwhile to refer to many of the definitions provided in the French version of the Schedule of Special Technical Clauses (CCTP) relating to these activities. Obviously there may be variations between different countries, but the overall chronology of events is very similar.

Works completion report

The contractor provides written notification to both the contract manager and the project manager of the date the works are expected to be completed, with at least one month's notice, and will keep both parties informed by issuing a provisional weekly schedule indicating the approximate waste volumes that the plant will be able to handle during the fine-tuning period.

Within one week of the date specified by the contractor, the project manager will inspect the plant to check that everything has been properly executed and complies with project specifications.

After completing the inspection the project manager will draw up on site a works completion report which both he and the contractor must sign. This report will provide details of omissions, imperfections or defects discovered (if any). The contractor must rectify these as soon as possible.

Fine-tuning the plant

No later than two weeks after the issue of the works completion report, the contractor will start to fine-tune the plant, having first given the project manager written notification of this.

During the fine-tuning period, which must not exceed 2 months, the contractor can stop the plant or run it under different regimes, for the purpose of making any adjustments required and ensuring that the plant operates at maximum efficiency. Preliminary testing is performed separately on each item of equipment. Tests are carried out under the supervision and at the expense of the contractor. They are designed to check that all the mechanical, electrical, electronic, thermal and hydraulic equipment functions correctly and satisfies the relevant norms, current standards of professional workmanship and the operating conditions prevailing in the market at the time.

In addition, the constructor of the plant will check the efficiency of the various treatments (operation at nominal and minimum furnace capacity, efficiency of flue-gas treatment, quality of the slag, etc.). Whatever happens, the plant must come on stream at the end of this period.

Semi-industrial production

This phase is when the plant enters into service under normal operating conditions, with the client regularly transporting waste for incineration.

The purpose of this phase is not to verify the plant's performance characteristics - these are measured during acceptance testing - but to check that the installation functions without any mechanical, thermal or electrical faults and without any other operating problems.

When the contractor believes that the plant is ready to commence the industrial-scale operation it was designed for, he gives written notification to both the contract manager and the project manager of the date when this can start.

No later than two weeks after this date the project manager must, unless there is a valid objection, release the plant for industrial service. This will be confirmed by an on-site report drawn up by the project manager and signed by him and the contractor. The date of commissioning is the date the report is signed.

Industrial-scale operation lasts for 2 months, on condition that it includes a minimum operating time for the installations, or the treatment of a minimum quantity of waste stipulated in the Schedule of Special Technical Clauses.

The contractor will supply the project manager with operating and maintenance instructions, the plans of the plant and will provide details of adjustment and safety parameters.

Plant management up to acceptance

Until the point of acceptance, the plant is managed under the supervision and responsibility of the contractor:

- *All the fine-tuning, repairs or modifications required are carried out under his supervision and at his cost.*
- *Energy, liquids and other consumables are provided free of charge by the client in limited quantities that satisfy the plant's requirements as defined in the provisional operating assessment. Nevertheless, the contractor is responsible for operating the plant, and will cover the cost of this, from the date that the operating contract comes into force.*
- *The contractor will pay the wages of the operating personnel.*

Acceptance testing

Acceptance tests are performed once the industrial-scale trial is complete.

The purpose of these tests is to determine the nominal and minimal treatment capacities, the treatment quality, the consumption and output of the different equipment under industrial operating conditions.

The tests involve the incineration, under a constant regime and for a specific number of hours, of a quantity of pre-weighed waste that is as close as possible to the tonnage processed at nominal and minimal capacity. The nature of the tests and their frequency, as well as the timetable for performing them, are mutually agreed by the contractor and the client, taking into account all the operating possibilities and exigencies. During the test period the contractor and the operating personnel supervise the plant's operation.

If a test control body needs to be called in at any time, the client will bear the cost.

The client, or any agent appointed by him, is responsible for supplying, installing and removing any temporary devices required to perform the tests.

The liquids and other consumable materials needed for the test phase are provided free of charge by the client in quantities limited to whatever is needed for the plant to operate while testing goes on.

If the results of the tests are disputed, an officially approved test body will be commissioned to perform another series of tests. The cost of the second batch of tests will be borne by whichever party the final results prove to be wrong.

The sequence of events leading up to the acceptance of the plant is illustrated in the following table:

- *The contractor provides written notification to both the contract manager and the project manager of the works completion date*
- *Date of works completion indicated by the contractor*
- *Works completion report indicated by the project manager*
- *Start of the fine-tuning period*
- *Contractor requests that the plant enters industrial service*
- *Project manager draws up report on the plant's industrial operation phase*
- *Works completion date (1)*
- *End of industrial operation phase and start of acceptance testing. Once testing is over, the acceptance is confirmed and the works completion date (1) is fixed by the client at the suggestion of the project manager.*
- *Client takes possession of the plant*
- *Additional acceptance testing, rectification of outstanding problems.*

Works completion does not imply that all the finishing work has been done, especially external landscaping (access routes, green spaces, fencing, etc.) and any works that are best performed after certain tests are over (painting, insulation, etc.).

(1) acceptance of the works takes effect on the date that the plant begins industrial operation.

8.2.4 Industrial operation

Once acceptance testing is complete and the results are conclusive, the ownership of the plant transfers to the client. The client and the plant operator are then responsible for plant management. The operating personnel have been trained and have had the opportunity to familiarise themselves with the installations over the two-month industrial operation phase, under the guidance of the project manager's skilled personnel.

The first year of industrial operation is tricky, firstly because some of the machinery has not been fully run in and there are often teething problems that disrupt the plant's operation, and secondly because the operator has not yet acquired enough experience to fully master the equipment.

During this period, which is in fact the period of warranty provided by the contractor and his subcontractors, the latter often visit the site regularly to fulfil their contractual obligations: rectifying outstanding problems, fine-tuning processes and adjusting machinery, as well as performing repairs.

These constant third-party interventions during the industrial operation of the MWT plant represent an aggravated risk in the event of a loss (fire, explosion, machinery breakdown, physical injury, etc.).

8.3 Comments on the business risks

The business risk is an unpredictable peril which cannot be mathematically calculated; it relates to dangers that are inherent in the commercial risk.

One of the principles of our economic system states that anyone pursuing an economic activity must, within the limits of their capabilities, meet any obligations ensuing from their activities.

This responsibility must not – indeed cannot – be transferred to the insurance company. It is therefore up to the contractor to take every appropriate measure to avoid any loss event, even if he incurs additional costs in doing so. The role of the insurer is to assume responsibility, within well defined limits, for losses which, despite all the precautions taken, occur as a result of sudden, unforeseeable and accidental events.

The business risk is influenced by subjective factors such as the level of competition, the search for new markets, the development of new products, expertise in the sector of activity and the tendency to take financial risks in relation to acquiring new business.

In the field of engineering insurance, the expression "business risk" is often accompanied by the attribute "uninsurable". It is certainly difficult to draw a clearly defined line between the pure business risk and insurable risks. The role of a company that offers engineering insurance is to protect the insured against the economic consequences of a material loss caused by a sudden and unforeseen event over a fixed period. The insured is not in a position – since it is not his job – to satisfy the demands of the constructor who wants to protect himself from the financial consequences of contractual guarantees that extended in the course of his business activities. But in the environmental technology sector these sorts of demands do sometimes occur.

The sudden escalation of environmental awareness and pollution controls has encouraged rapid technological advances over the last decade or so. Whereas in the eighties waste incineration plants in most countries were practically limited to a furnace, a filter system and a chimney stack, nowadays these installations are based on a whole range of high-tech processes designed to produce "zero" pollution. Furthermore, cogeneration plants fuelled by biogas, waste sorting and recycling plants, pyrolysis or plasma furnaces should all help to reduce environmental pollution to a minimum.

Contractors have had to make enormous efforts to keep up with the frantic pace of technological progress. They have accepted contracts with performance guarantees which they are not certain they can meet. The time taken to perfect new processes or equipment has had to be drastically cut. A good many products are not able to be properly tested until they enter industrial service, with all the risks and surprises this entails.

In view of tougher environmental legislation and fierce competitive pressure, the contractor is obliged to assume new risks which are becoming more and more onerous. In addition, regulations are still at the evolutionary stage, which makes the task of constructors and investors even more difficult. Frequent announcements of revolutionary processes on the market also increase the pressure on contractors.

Given these circumstances, an insurer who offers conventional cover, or perhaps slightly extended cover, is inevitably confronted with the same problems as his client, i.e. having to provide cover for risks of an entirely innovative nature.

Among the different types of engineering insurance cover there are a number of borderline cases where the insurer faces the following dilemma:

"What are the risks that I can cover without exceeding the point where I take the contractor's place?" The essential role of the contractor is to run risks inherent in every industrial and commercial undertaking (research and development into new products, production, sales, etc.) with the aim of assuring the success of his business. If the insurer is encouraged to cross this barrier, should he not automatically share in the profits generated by his client's activity?

One of these borderline cases involves providing cover for the consequences of a material loss caused by a design fault, poor execution of works, or a material defect in the prototype installations. This limit is sometimes even exceeded when the insurer agrees to pay the cost of repairing the faulty part.

Contractual guarantees accepted by the contractor on signing the contract are typically business risks that cannot be transferred to the insurer. Examples include:

- Performance guarantees relating to production capacities, output, electricity consumption, and other consumable materials (water, chemical reagents, etc.), operating parameters (pressure, temperature, throughput, etc.), noise pollution, emissions, etc.
- Product guarantees (granulometry, water content, resistance to corrosion and heat, insulating properties, appearance, colour, toxicity, etc.)
- Guarantees of availability and reliability
- Meeting deadlines for completing the works and commencing industrial operation
- Any other guarantee contained in the contract that is particular to a product, a piece of work, or a service.

In order to cover the consequences of these guarantees not being met, the client fixes contractual penalties which can be as high as ten percent of the total market value. Furthermore, the client may even refuse to accept the installations.

8.4 Underwriting recommendations

Modern waste treatment plants are complex installations, which makes risk analysis and premium rating difficult. From a technical viewpoint, these installations can be grouped, in certain respects, in the same class as power stations and may also present similarities with facilities found in the chemical and petrochemical industry. It is not easy for insurers to evaluate with sufficient accuracy the technical problems and the claims potential inherent in each new business, so as to take these into account when pricing the risk and formulating the insurance cover. In our opinion underwriting this class of business requires close collaboration between insurers and their clients.

New treatment systems and processes are being continuously developed by industrialists, and are advancing much more rapidly than the premium-rating tools available to underwriters. In this respect, it must be pointed out that the premium rates shown in the tariff guides are based on experience to date and therefore need to be adapted to reflect specific parameters. Even for experienced underwriters, it is difficult to evaluate the true price of the risks inherent in this technological evolution. Furthermore, fierce competition between insurers is a dominant factor, so that the prudence generally advisable for risk assessment often takes second place.

When performing a risk analysis of new business, we recommend that underwriters pay special attention to the following aspects:

Does the contractor have sufficient experience in this domain? How many similar MWT installations has he already completed?

This question is equally applicable to designers and constructors of the principal equipment (furnaces, boilers, flue-gas treatment systems, catalysers, residue treatment systems, etc.). Municipal waste is a very heterogeneous mix of combustible materials that constantly brings surprises in the combustion process and subsequently in the composition of the flue gases. Extensive experience is required to be able to master all the complex techniques involved (choosing the right materials, dimensioning the equipment correctly, defining the control and operating systems, etc.). A high degree of theoretical and practical expertise in complementary technologies is certainly an important factor but in itself does not generally entail a complete mastery of the subject from the outset. A leading international constructor in this field believes that a specialist in this industry must allow at least 6 years between the conception of a new product and its industrial commercialisation.

The choice of suppliers and subcontractors plays quite a significant role in the quality of the project. Equipment such as electrostatic precipitators, bag filters, activated carbon filters, catalysers, steam turbines, extractor fans, etc. are also key components in the treatment line. Damage or malfunction in any one of them will inevitably cause a serious delay in the commissioning of the MWT plant.

Certain specialised services can only be performed by a limited number of suppliers. Specific examples include the interior lining of flue-gas wet scrubbing systems, or even the refractory bricks and pneumatic transport systems that handle the flue-gas residues after dry or semi-dry scrubbing. Subcontracting work to small local companies can also have disastrous consequences on the final outcome of the project.

The positioning of certain equipment also requires careful checking. For example, the catalyser must normally be installed downstream of the flue-gas treatment system to prevent it from becoming prematurely fouled (remember that the catalyser operates at temperatures around 350°C and therefore requires a source of energy to reheat the flue gas). Positioning the catalyser upstream of the flue-gas treatment system, i.e. before the gases are cooled, must be avoided at all costs. It should also be noted that, as far as the process is concerned, other equipment can be installed in positions that are unsuitable purely on grounds of economy. One example is the extractor fan, which is positioned in a hot area so that it does not have to be protected against water corrosion (in this case, the flue-gas treatment system operates under pressure and the fan is exposed to corrosion when the plant is idle). Another is the bag filter: if this is situated in an excessively hot area close to the boiler outlet, there is a risk of the filter bags being destroyed (depending on the type of fabric, operating temperatures range between 120°C and 220°C).

Obviously a lot of negative experiences have been recorded as a result of these problems, which – it must be emphasised – were in each case caused mainly by deciding to run a risk in order to reduce the overall cost of the MWT plant.

It is important to remember that these experiences apply almost exclusively to countries such as Germany, Switzerland or Sweden, where the construction of high-performance flue-gas treatment systems commenced several years ago. It would be unfortunate if the same errors were to be repeated in other countries where these technologies are only just being introduced. In this respect, it is interesting to note that loss prevention is one of the services offered by insurance companies that is often appreciated by clients. In a good many cases loss prevention benefits not only the insurer, but primarily the owner and the operator of the plant, because financial losses following material damage are only insured in very rare cases and can jeopardise the company's very existence.

The list would be incomplete without looking at protection against fire during the construction and operation phase. Solely on the basis of major fires that have broken out in flue-gas treatment systems in recent years, the premium needed to cover this class of business (Erection All Risks) has to be significantly higher than the premiums currently encountered on the market. Given the difficulties involved in setting a premium that reflects the risk, it is absolutely vital to impose fire prevention measures in the special conditions of insurance policies (for more information, please refer to Swiss Re's publication "Fire protection on building sites"). These conditions must be verified by regular site inspections.

Apart from the engineering risks just described, the plant's exact geographical location also plays an important role, both as regards geological and weather conditions, such as whether it is:
- in an earthquake region
- directly on the coast
- in a region that experiences heavy storms
- near a water course or in an area susceptible to flooding
- built on poor terrain (old landfill, hardcore, swamp, etc.)

One of the interesting engineering insurance aspects connected with this class of business is risk analysis and underwriting for Advanced Loss of Profits and Machinery Loss of Profits policies. Encouraged by their financial backers, clients who commission MWT plants are now showing a greater interest in taking out these types of insurance policies.

If a new plant is being constructed, the client can take out Advanced Loss of Profits cover in combination with Contractors' All Risks or Erection All Risks cover. If the MWT plant is already in service, the owner can insure himself against financial losses resulting from production shutdown by taking out Loss of Profits cover for losses caused by machinery breakdown or fire.

The sum insured (annual gross profit) usually comprises the following elements:
- The profit from operating the plant
- Fixed costs such as provisions for rent, insurance premiums, interest on loans, employees' salaries, etc.

In the area of waste treatment plants, there are numerous difficulties associated with Loss of Profits policies.

First of all there are problems with the definition of the interests to be insured, which can vary substantially from one project to the next (with Advanced Loss of Profits policies, only the plant owner can be insured and sometimes the financial backers as well).

It is often difficult to accurately determine the real loss in gross profit because there are frequently agreements between regional operators of MWT plants to allow a municipal authority to continue refuse collection even if its own MWT plant suffers a major breakdown that takes time to repair. In such cases the losses will be limited to additional transport costs and the loss of revenue from the sale of surplus heat.

In the erection and testing phases, the risk is substantially higher than during the operating phase. This is because no stock of spare parts exists yet, fire-fighting systems are not operational and the operating personnel are not yet sufficiently familiar with the installations.

Material damage often occurs – even minor damage – that causes a serious delay in installing machinery or a prolonged shutdown to allow a process to be improved or a fault repaired.

Unfortunately not all the factors that influence the time taken to complete the repair, and consequently the total business interruption sum, can be identified in advance and are difficult to assess at the time the policy is taken out.

Any party taking out Advanced Loss of Profits or Machinery Loss of Profits policies must realise that insurance cover cannot be granted without certain limitations on cover and that the price charged – which may appear rather high at times – is purely a reflection of the substantial risk carried by the insurer.

To complement this information and advice, we include a few conclusions drawn from the loss statistics for MWT plants:
- flue-gas treatment systems are by far the biggest cause of claims;
- fire losses, some of them with catastrophic consequences, have been covered by Erection All Risks policies because they often occur at the end of the erection and testing period;
- a lot of damage has been caused by design errors and defective materials;
- with machinery breakdown, it is the furnace/boiler unit and more specifically the evaporator tubes of the boilers which are the most common cause of losses. Here again, damage is usually the result of design errors (gas flow, abrasion, corrosion);
- with Advanced Loss of Profits policies, there is still not enough business to enable conclusions to be drawn on the results of this branch.

8.5 Special clause

Erection All Risks insurance: special clause for the construction of MWT plants.

With the commencement of commissioning and testing activities, any damage to catalysers, refractory bricks, equipment made from polymers and other linings such as ebonite, rubber, etc. will only be reimbursed if they are:

- The direct result of a loss sustained by other insured parts that is covered by Erection All Risks cover.
- Caused by mechanical effects that are not the direct consequence of permanent operating conditions in the installation.
- Caused by a fire, lightning or an explosion, on condition that all the fire prevention measures have been respected.

Remarks: catalysers are considered to be damaged if:

- There is a modification to the original condition of the catalytic elements
- Their efficiency is significantly reduced, as long as this is supported by measurements.

The measurement procedures for determining the degradation of the catalyser's performance are to be stipulated in the policy before it comes into force.

The indemnity sum is based on the current market value.

Special exclusions

Corrosion damage to the linings' support material (cladding, pipework, steel casing, etc.) are not covered in any event.

Performance degradation in the catalysers is not covered if this is due to fouling or pollution, unless this is the direct result of a loss included in the Erection All Risks cover taken out on other insured parts.

Damage or performance degradation to the catalysers are not covered if they are due to the catalyser being incorrectly positioned in the flue-gas treatment plant.

Glossary

Chemical elements

Symbol	Element	Symbol	Element
As	Arsenic	Mn	Manganese
C	Carbon	N	Nitrogen
Cd	Cadmium	Na	Sodium
Ca	Calcium	Ni	Nickel
Cl	Chlorine	O	Oxygen
Cr	Chromium	Pb	Lead
Cu	Copper	S	Sulphur
F	Fluorine	Sn	Tin
H	Hydrogen	V	Vanadium
Hg	Mercury	Zn	Zinc

Chemical products

Chemical formula	Scientific name	Common name/form
CaO	calcium oxide	quick lime
$Ca(OH)_2$	calcium hydroxide	dead lime
$CaCl_2$	calcium chloride	
$CaCO_3$	calcium carbonate	gypsum
CO_2	carbon dioxide	carbonic gas
CO	carbone monoxide	
HCl	hydrogen chloride	hydrochloric acid
HF	hydrogen fluoride	
H_2O	hydrogen oxide	water
$NaCl$	sodium chloride	cooking salt
$NaOH$	sodium hydroxide	caustic soda
NH_3	ammonia	
NOx	nitrogen oxides	
PP	polypropylene	
PE	polyethylene	
PVC	polyvinyl chloride	
PCDD	polychlorodibenzoparadioxins	dioxins
PCDF	polychlorodibenzoparafurans	furans
SO_2	sulphur dioxide	sulphuric acid

Definitions

Adsorption	Retention, on the surface of a solid, of molecules of a gas or a substance in solution or suspension
Emission	Discharge of pollutant substances
Fly ash	Ash, soot and dust contained in the combustion gas as it leaves the combustion chamber
Heavy metals	Mainly lead, chromium, copper, manganese, cadmium, mercury, nickel, arsenic
H_u	Lower heating value
Immission	Concentration of pollutants damaging to human beings and the environment
Leak air	Air penetrating parts of the installation that are not completely air-tight
Primary air	Air forced under the grate to assist waste incineration
Scrubbing residues	Residues from the scrubbing of flue gases produced during the incineration of municipal waste
Secondary air	"Post-combustion" air, needed for the combustion of unburnt gases and for the initial cooling of combustion gases
Slag	Combustion residues recovered from the boiler output
Tertiary air	Air used to cool the combustion gases prior to purification or air for cooling the interior side walls of the furnace
Unburnt substances	Organic matter that was not burnt during the combustion process

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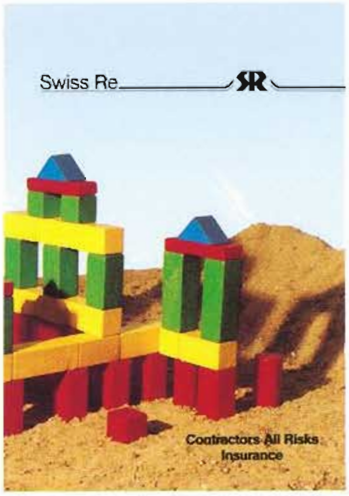
Von Roll Environnement S.A., Zurich
Widmer & Ernst Umwelttechnik, Zurich
Deutsche Babcock, Krefeld.

Previous Engineering publications

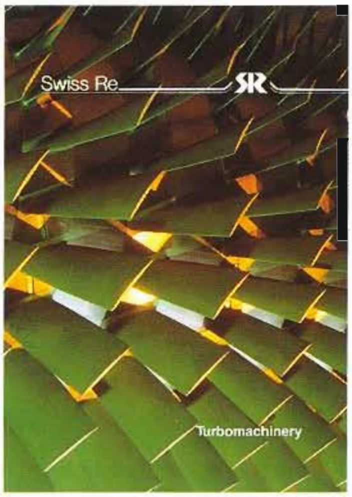


Contractors All Risks Insurance

Construction projects are often of a distinctly prototype character; it is important therefore for successful underwriting that all aspects are taken fully into account.

The first part of this publication outlines the insurer's influence on the various project phases and the insurance-related clauses of the standard FIDIC contract. The second part deals with the sections and scope of cover of the CAR policy. The third part contains indications on risk assessment, loss prevention and claims handling.

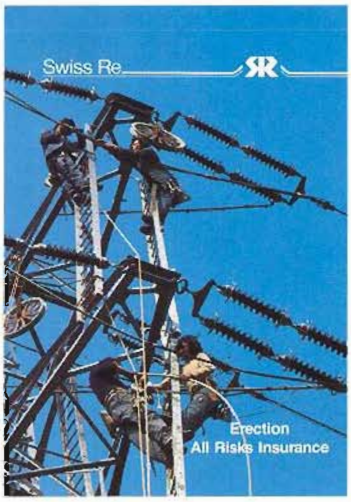
Year of publication: 1990; available only in English.



Turbomachinery

This Engineering brochure is intended to familiarise engineering underwriters with the complex subject of turbomachinery and aid them in assessing these risks accurately. It considers many of the technical factors related to turbomachinery underwriting during the installation, commissioning and operating phases.

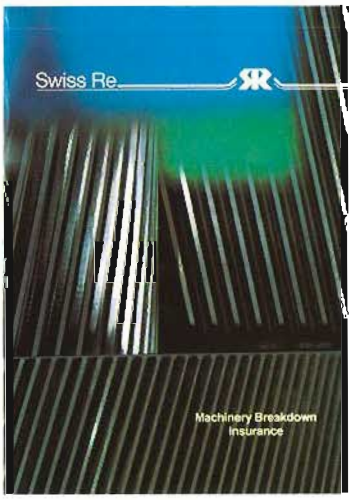
Year of publication: 1990; available only in English.



Erection All Risks Insurance

This is a guide for insurers and engineers to acquire expertise in the field of Erection All Risks insurance. EAR insurance protects principals and contractors and also manufacturers erecting plants and machinery. The booklet deals primarily with the scope of cover and underwriting considerations as well as with claims handling. Photographs illustrate the risk categories and types of damage.

Year of publication: 1976, revised 1988; available in English and Spanish.



Machinery Breakdown Insurance

Following a survey of the history of the machine industry, and the insurance of machinery and industrial plant, the publication concentrates on aspects of successful underwriting in Machinery Breakdown insurance. It outlines the methods used by insurers to assess and rate the risks resulting from the operation of technical installations.

Year of publication: 1991; available in English, French and Spanish.

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Swiss Reinsurance Company
Public Relations
Mythenquai 50/60
CH-8022 Zurich
Fax: 41 1 285 2023

Photographs

Cover photo: Typical packing used in one of the stages of the flue-gas scrubbing towers. A large specific surface area facilitates contact between the liquid and gaseous phases, thereby improving the efficiency of flue-gas purification
Von Roll Environmental Technology, Zurich, Switzerland

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