Refractories in the Global Incineration Industry

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One of the most important and very possibly the most urgent issue facing society today, is the preservation of the environment to maintain the quality of all forms of life on the planet. The US Census Bureau and the United Nations Organisation are both in general agreement that the population of the globe is expanding from its current level of about 7,33 billion at a net rate of over 35 million souls each year and of course this rate of rise is itself increasing. The World Bank has estimated that in Europe and in North America, the growth rate will probably be around 1,5 %/a. This inevitably results in greatly increasing requirements for both the consumption of products and the disposal of a wide range of waste arising from this consumption in its many varied forms. It would appear therefore that the logical solution of not creating so much waste in the first instance is never going to be a wholly viable option.

Introduction

As the population grows worldwide, the problem must be becoming more difficult rather than easier in spite of considerable efforts by everyone to at least slow down if not halt the present currently perceived decline in the quality of life as measured by factors such as atmospheric temperatures. To some extent, we all also experience the pollution of rivers and oceans by plastics as well as other, often toxic contaminants in earth and soils. Legislation is currently now a major factor in determining how the situation develops in future. Substantial new regulations governing waste disposal are different in Europe and the USA, and very different elsewhere in the world although everyone is now attempting to achieve the same desirable outcomes in their own sometimes unique situations. It is readily apparent that even different countries within defined geographical areas of the world such as Europe have very different politics, infrastructures, technology and capabilities. There are even differences in most GB local government areas although strenuous efforts are currently being made to rationalise these. Waste disposal in a country with a low population density and a substantial land mass is necessarily treated very differently to that in a country with a high population density and a low availability of suitable land space for disposal of detritus in traditional landfills.

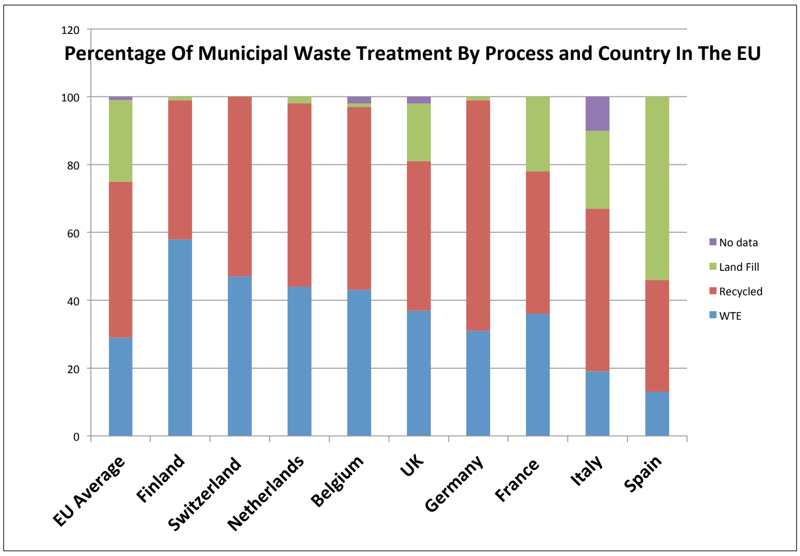

Fig. 1 Disposal of MSW by process and by country in Europe

This report attempts to review how rapidly advancing technology in both refractories materials and engineering plays a key role in some of the available options. These include Municipal Solid Waste (MSW), Waste to Energy (WTE), and several other specialised processes technologies, such as hazardous waste disposal and pyrolysis. Municipal waste disposal has undoubtedly grown over the last 50 years, but so it must be said, has problems in the design and operation of the more specialised plants. Indeed, some refractories have been pushed up to and even far beyond their normal limits of use. The correct specification and application of the available refractories can therefore be of critical importance in the success of the optimum operation of each furnace. This report does not seek to confront the wider underlying political or ecological issues directly, but to look at existing processes for thermal disposal of waste in some detail, and assess how they may develop in future as part of a sensible balanced solution.

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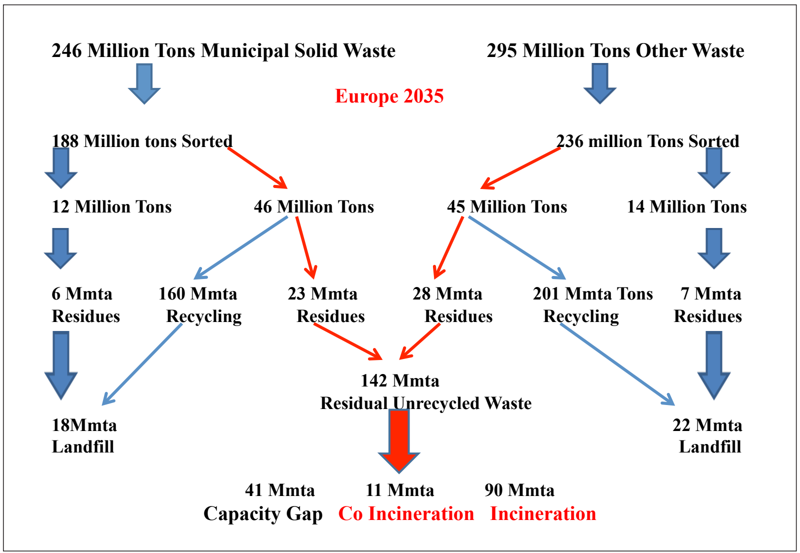

Fig. 2 **The potential shortfall for disposal within the Circular Economy**

The total municipal waste handled each year in Europe is thought to be around 130 Mt/a of which about 70 Mt/a (53,8 %) is recycled, 35 Mt/a (26,9 %) is incinerated, and 25 Mt/a (19,3 %) is sent to landfill. Germany currently recycles more than half of its municipal waste to reduce the tonnage going to incineration and landfill, with the proportion currently being incinerated being about 35 %.

In Spain, where public opposition to incineration has been particularly high, only about 15 % of its municipal waste is incinerated, and while still not having been able to progress recycling much beyond 35 %, almost 50 % is still having to be sent to landfill.

Other countries outside Europe also vary widely. In 2014, for example in USA approximately 258 Mt of municipal solid waste was generated in total. Over 33 Mt (12,8 %) were combusted with some energy recovery, while 89 Mt (34,5 %) of this waste was recycled and composted, and a further 136 Mt (52,7 %) were disposed of in landfills (Fig. 1).

Circular Economy

Originally, the disposal of municipal and indeed other very different types of waste and by-products by incineration was not only welcomed by most members of society, but in fact deemed absolutely essential in many countries around the globe to maintain public health. Since that time however, it has become very controversial in most developed countries. In Europe for example, the European Commission promotes the Circular Economy as an ideal, and environmentalists now firmly insist that there must be zero incineration in the overall equation which at present is far from being the case. One reliable source has estimated that about half of the world's almost 800 operating municipal waste incinerators are currently in service in Europe. The remainder are mainly in North America, and in parts of Asia such as Japan. European statistics are neither fully up to date, nor comprehensive, but the indications are that Germany may handle over 50 Mt of waste annually with France about 20 Mt and GB around 10 Mt. The other 25 countries in the EU make up the balance of the estimated total of 130 Mt of waste.

The situation is further complicated, however, because each country obviously has different population numbers very and different infrastructures. The demands of the Circular Economy in Europe mean that increasing amounts of waste will necessarily need to be handled with much higher levels of recycling, and with the consequent very much lower levels disposal by incineration and by landfill.

To assist achieve the proposed ideal Circular Economy, the EU have even suggested that all investment in new incinerators plants throughout Europe is reduced to zero, although this hardly seems feasible if the estimates of waste to be generated in future are at all accurate (Fig. 2).CEWEP, the Confederation of European Waste to Energy Plants, is the umbrella association of the operators of Waste to Energy Plants, representing about 410 incineration plants operating within 23 of the countries operating inside the EU.

Their calculations show that 142 Mt of operating waste treatment capacity will be needed by 2035 in order to fulfil the currently set EU targets on municipal waste disposal, assuming of course, that the ambitious recycling targets will be achieved. If incineration plant capacity is frozen or only grows minimally, then there needs to be a very large increase in recycling or several very significant problems will very soon arise. It also ignores the fact that waste to energy plants have a very beneficial recovery of many terawatts of electricity, and also in some new plants, additional terawatts of sensible heat which is used in projects such as district heating. It is claimed that the current energy recovery in Europe if collected, and focused could see Scandinavia through a very long severe winter.

There is also some metal recovery and usable ash recovery for a range of cementitious byproducts. For designers and manufacturers of a new incinerator plant, all of this does not sound like good news although refractories manufacturers and installers can certainly take comfort from the substantial annual maintenance and the more extensive smaller interim repairs which all plants require.

Development of the process and lining materials

As has been reported above, MSW is extremely variable depending on many factors. The average composition of such waste in Europe has been established over many years. The composition, however, can be very different in one incinerator at different times of the year and equally very different in one unit compared to another (Fig. 3). In spite of this, the incineration processes used for the MSW itself is relatively very straightforward.

After charging the waste, which although solid may contain significant moisture content, it is first initially dried and generates steam as it rises rapidly in temperature up to about 150 °C. Between the temperatures 150–650 °C, organic materials are depolymerised and volatiles are emitted. In the presence of excess oxygen, the volatiles

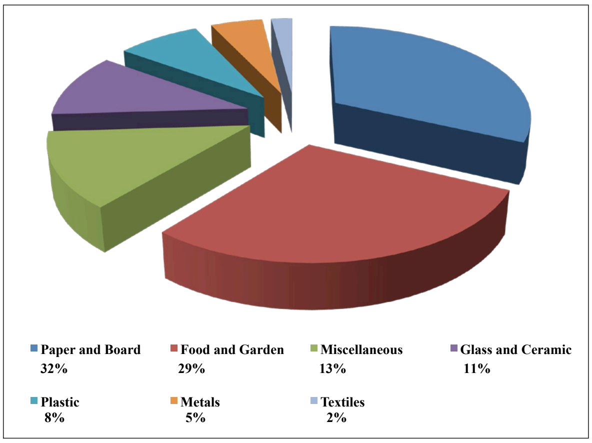

Fig. 3 Typical composition of MSW in Europe

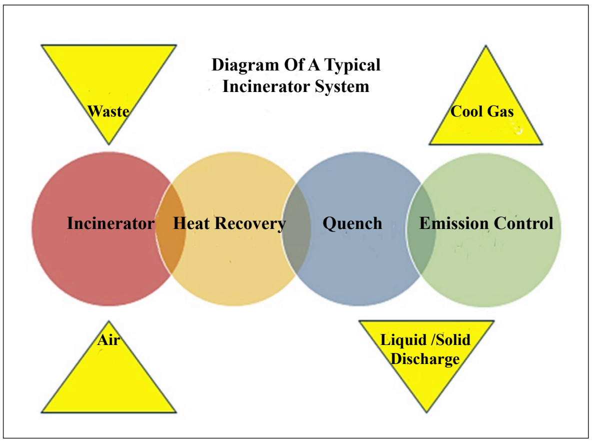

Fig. 4 A diagrammatic representation of the MSW incineration process

start to ignite and combustion is completed in the mixing, and secondary combustion chambers. Increasing application of heat up to in excess of 800 °C converts any remaining fixed carbon into carbon dioxide. Other mineral constituents will usually not burn, but may partially melt, and are collected in the ash pit with ash containing silica, lime and other inert elements (Fig. 4).

During the early phase of the introduction of incineration, most furnaces featured a relatively unsophisticated design with a static grate, and were constructed at that time mainly from high duty firebricks. The furnaces were usually relatively small and mainly had sprung arch roofs. The feed into the early incinerators was through a front charging door, and was extremely variable with consequent enormous differences in the size texture as well as calorific value of what was being charged.

The charging itself was intermittent and feed not always tightly controlled for the ideal or even the optimum combustion. This resulted in uneven wear and short lives of refractory components. The main wear was at grate level where high and usually fluctuating temperatures caused slagging and spalling. The door was also a weak point, being very prone to spalling, and was often installed in high alumina castable. There was virtually no insulation.

These units rapidly evolved in many cases to a multi-chamber format, with a more zoned type of construction, to ensure not only the better combustion of the waste, but also the secondary combustion of some of the evolved particles and gases, many of which could be noxious. The filtration of emissions was eventually introduced along with some form of energy recovery (Fig. 5).

Very few of these smaller batch type furnaces remain today, and as the volume of very variable refuse increased greatly, then furnaces became very much larger, continuous in operation, and usually incorporated an inclined moving grate in the form of reciprocating alloy steel bars or large rotating cylinders to ensure that heat and oxygen were well circulated into the charge to assist complete combustion in as short a time frame as possible. Charging areas, which were relatively cool but prone to abrasion, and some spalling were constructed in high duty firebricks or abrasion resistant refractory concrete. The main combustion chambers were upgraded to at least 60 % alumina bricks or castable, and normally well insulated externally. The roofs, which had a larger span than previously but were often high enough to avoid excessive temperature, were typically installed using a proprietary suspended brick system and external insulation. The grate itself was high alloy steel bars or large rollers with excess cold air being blown into the furnace from underneath the grate which helped reduce wear and extend life. The main wear area developed on the sidewalls immediately above the grate level. These were exposed to continuous very high temperatures, and suffered slagging which could eventually make the wall unstable and impede the flow of feed in the furnace. The lower sidewalls above grate level were thus often lined with a range of newer special refractories. Originally, these refractories might have consisted of phosphate-bonded high alumina bricks or plastic because it was believed that this material afforded extra protection against both hot abrasion and slag attack. It soon became apparent, however, that with the increasingly severe conditions, silicon-carbide air cooled bricks or in some cases air cooled alloy steel castings were

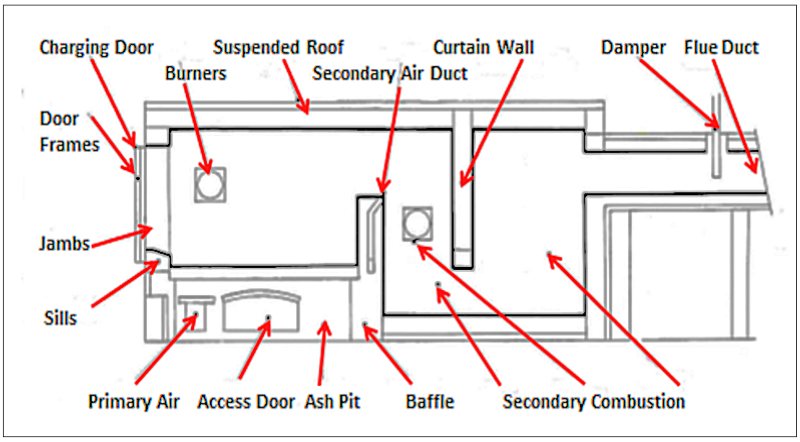

Fig. 5 Fixed hearth batch type incinerator for MSW

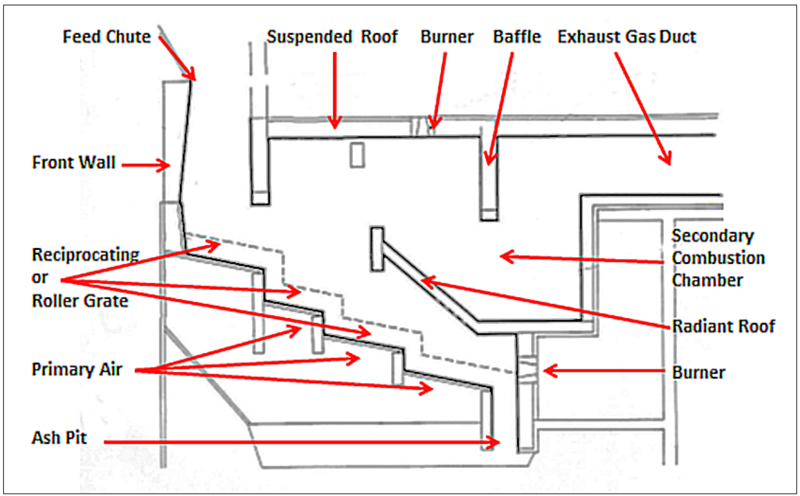

Fig. 6 Large continuous high capacity moving grate incinerator for MSW

necessary for optimum cost effectiveness. Fused grain refractories with alumina spinels and even fused cast refractories have even been used to reduce wear (Fig. 6).

Such continuously operating furnaces have grown greatly in size and are now the norm. Amager Bakke/DK, the plant built in 2017 to incinerate Copenhagen's waste, is said to have a capacity of 400 000 t, and is designed to incorporate a ski slope on the roof to help it blend with the landscape and provide recreational facilities. The biggest and most ambitious waste to energy plant in the world, which is also Danish designed, is due to be built in 2020 near the city of Shenzhen in China. It is claimed, that this plant will have a capacity of up to about 1,75 Mt/a, and the 66 000 m² of inclined roof will be fitted with solar panels to generate additional electrical power. Even at this enormous size, the plant will probably still only handle about one third of the municipal waste currently generated by the city's 20 million inhabitants. It will also be a major consumer of a wide range of refractories.

Hazardous waste incineration

There are specialist operations such as that operated by a major waste disposal organisation near Southampton in GB which exclusively handles hazardous waste. This waste includes spent lubricants, controlled drugs, pesticides and some very low level radioactive materials as well as a wide range of chemicals some of which may be charged straight into the furnace in steel drums. This waste must therefore be incinerated at higher temperatures than normal, and always in excess of 1000 °C. The process involves much more stringent treatment of emissions, residues and ash than is normally carried out on MSW disposal. The ash itself, typically contains measurable amounts of copper, barium, cobalt, zinc, nickel sodium and potash as well as silica and lime. This type of unit is typically a short rotary kiln, about 12 m long, and 4 m internal diameter with a 300 mm thick high alumina bricks lining backed by 50 mm of hard firebricks as insulation, and which also acts as a safety layer. The bricks in each zone contain progressively higher alumina contents from 60–90 % as the temperature rises, and some may be impregnated by proprietary nanosized refractory particles to boost alkali resistance in service. A significant refractory problem area in such a process is the kiln discharge nose ring. This was originally constructed sometimes using special shaped alumina chrome spinel blocks, but has also been formed from monolithic materials, including precast blocks with high silicon carbide content or even guniting.

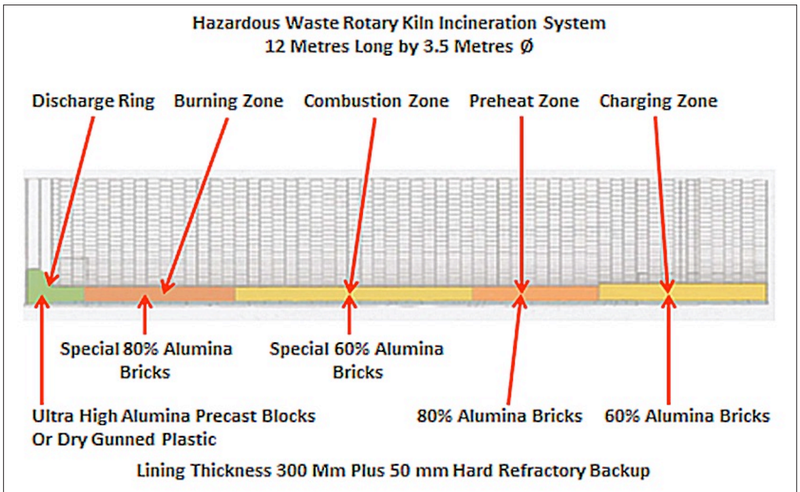

Fig. 7 Rotary kiln incineration process for hazardous waste incineration

Rotary kilns

Other rotary kilns have increasingly been used as a means of incinerating MSW, not only because it assists communities dispose of large quantities of waste which would otherwise require alternative arrangements to be made, but also because it is normally much cheaper than conventional fuels which are required in large volumes, and at high cost to operate the new generation of large cement kilns. One of the first instances of such processes, where alternative fuels can be used to supplement the normal fuel, was promoted from North America.

Small compressed bales of municipal waste were injected through a special hatch in the kiln shell in the preheat section of a cement kiln, every time the kiln completed one entire revolution. The system could also be used to dispose of automobile tyres when substituted for the bales of waste. Tyres and other spent oils have also been introduced into some preheater towers of dry process kilns. Some plants then used shredded and pelletised tyres which gave a much more even and controlled combustion.

Many more plants now use alternative fuels on a daily basis, and these are sourced as shredded paper, plastic or many other variable materials. Not the most ideal fuel, but the one with possibly the best aroma must be used coffee grounds. To begin, with no special changes to refractories specification were implemented with the increased use of alternative fuels derived from a wide variety of domestic, commercial and industrial waste. It was rapidly found, however, that not only could this waste generate some high temperature hot spots in areas such as the kiln hood, but also that there was a build-up of alkalis in the system. This could result in heavy additional refractories wear in any area where the temperature gradient fell to where alkali vapours could condense, and exacerbate severe slag attack. Such areas not only included tertiary air ducts and dampers, but even the main kiln lining where the temperature gradient behind the hot face often promotes a liquid slag phase. There may also be high wear in refractories in the ducts and cyclones in the ancillary plant. Serious consideration is now being given to improved alkali resistance in all refractories that may be affected by exposure to the combustion gases in the system, since it is unlikely that the use of alternative fuels from waste will decline in future for logistic and economic reasons. As a result, upgrades in flue gas filtration and treatment are also being implemented.

Sewage sludge incineration

One high capacity solution for the disposal of sewage sludge by incineration is the multi-hearth furnace. Filtered and dewatered sewage sludge is introduced onto the top hearth of a multi-hearth unit which might typically have 11 hearths, and be over 10 m in diameter. The sludge is progressively dried and combusted by transferring it down through the multiple grates using rotating rabble arms.

These turn the feed over many times, and progressively discharge it downwards alternatively through a gap in the hearth around the central shaft or through holes at the periphery of the next, until material is completely burnt and discharged as a small amount of inert ash which is easily and cheaply disposed of. These hearths, which were traditionally built from firebricks in an inverted dome shape, are being replaced with high-alumina ultralow cement castable which is either cast in situ in shuttering or formed from large precast blocks. Casting in situ requires continuous pours of up to 30 t, and very careful curing and drying to avoid explosive stalling. The use of large precast blocks built on collapsible formwork means that the shapes, which were previously cast, cured and dried under factory conditions, can be quickly and easily installed, and don't need such lengthy commissioning periods which shortens the construction time and reduces the overall cost.

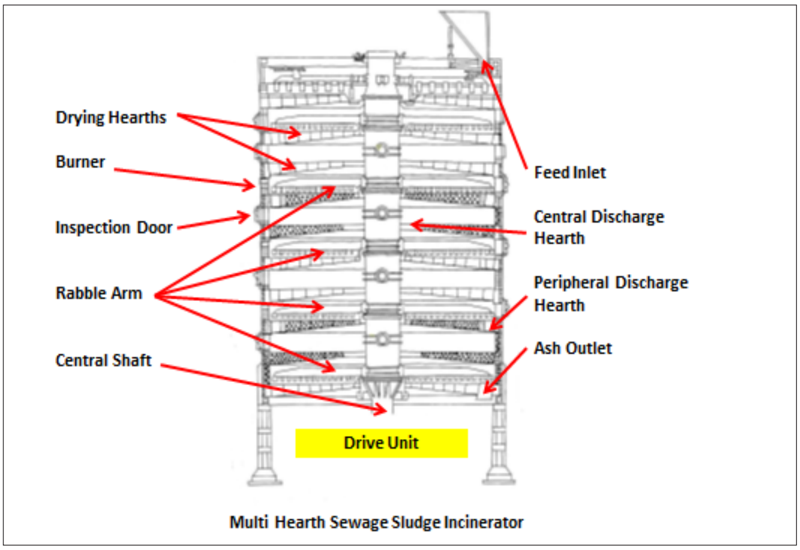

Fig. 8 Typical multi-hearth sewage sludge incinerator

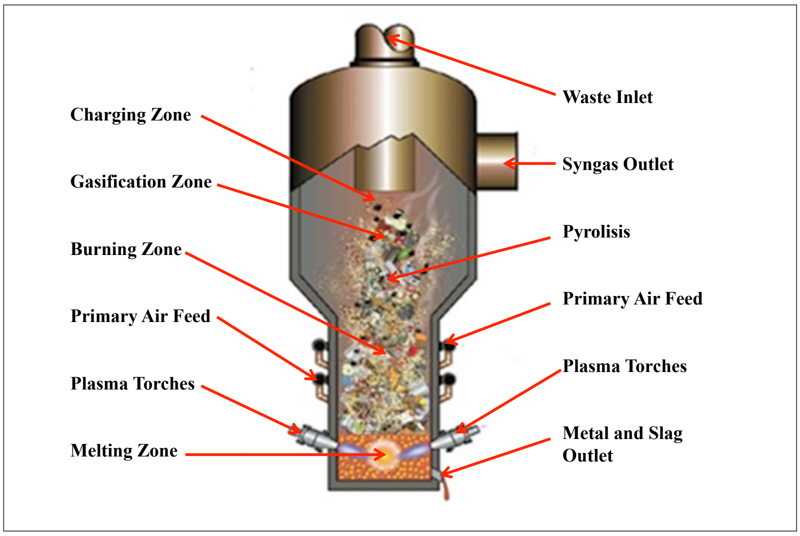

Fig. 9 One design of a MSW plasma arc incinerator

Clinical waste incinerators

In GB, medical waste is split into four main categories which are designated as infectious, sharp, anatomical and medical types. The collection handling and disposal of all of these are covered by stringent rules and regulations.

In the past, each hospital might typically have had its own small incinerator. This would have been a small fixed grate horizontal furnace. It would have been charged with sealed plastic boxes from a chute at one end. The waste would then have been pushed into the furnace and along the grate by a hydraulic ram. Warm excess combustion air was introduced into the furnace from underneath the grate. The waste moved slowly, along a perforated grate between two very large refractory beams which formed the lower sidewalls. Additional fuel and some air were introduced through burners in the beams, and the combustion zone would operate at over 1200 °C. Solids would be discharged into the ash pit, and gases would be evacuated through a flue system with dust and emissions controls. The lining of the side beams and sloping furnace walls would be con-

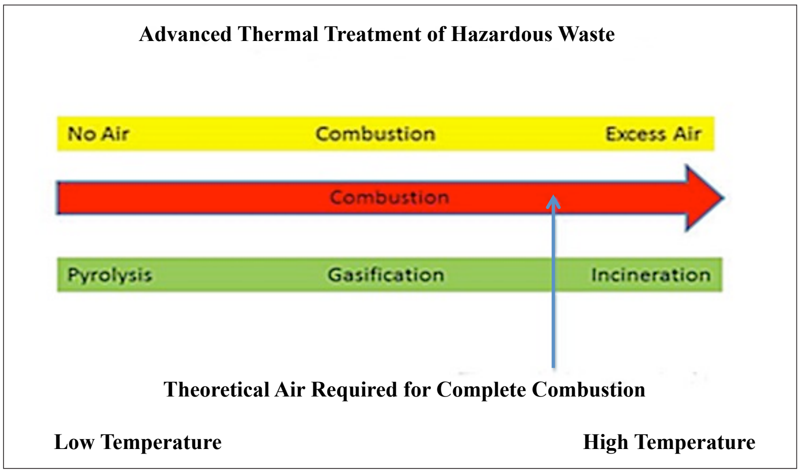

Fig. 10 The range of thermal process types for future waste disposal

structed from high alumina precast blocks. The roof could be in a medium alumina castable on anchors as would the flues.

The refractory operation and life of such furnaces was generally not a major problem, but the system of using such small individual furnaces itself was designated as being unsatisfactory in GB. It has been replaced with a collection system which now disposes of waste in larger centralised incinerators. Many judge the new system unsatisfactory due to the lack of sufficient capacity arising from increased levels of waste, and the more onerous rules. Policy for this essential disposal is being fiercely debated on a logistical and technical basis.

Chemical waste incinerators

There is such a wide range of chemical waste Incinerators that it is impossible to cover them adequately in a short report such as this. The processes are as varied as burn pits constructed from high duty firebricks in the Middle East to flare stacks and sulphur burners, which are also associated mainly with the petrochemical industries worldwide. The design and the lining materials cover the complete range of refractories materials, up to very high alumina bricks and monolithics in rammed and gunned format, along with a range of insulation products.

Biomass incinerators

Where wood and wood products must be incinerated for any reason, such as to dispose of the waste arising from chipboard, which may be impregnated with resins and other chemicals or wood chippings and sawdust, which in some circumstances can be explosive fluidised, bed furnaces can be used. These are generally vertical cylindrical units, where the refractory linings are mainly monolithic. The hearths, which are normally in abrasion and spall resistant high alumina castables, can be cast and preassembled as precast blocks or cast in the furnace. Primary air and fuel are introduced under pressure through the hearth and fluidises a bed of sand or aggregate on and in which the feedstock burns. The lining above the bed level is often in very high alumina material backed by substantial insulation to withstand temperature alkali attack and hot abrasion, as well as the possibility of thermal shock.

Maritime incinerators

The development of small compact incinerators for use aboard sea going vessels was pioneered in Norway many years ago. Kay Lindegaard of Oslo, which was formed in 1932 and were distributors for Plibrico, even started a separate incinerator division. Production of these units spread initially to Poland, and to then Croatia and South Korea. Some of these were assembled and lined initially in factories on land and fitted into the vessels which they were to serve. The linings were then mainly monolithic and consisted principally of high alumina castables, rammables and plastics.

Subsequent lining repairs could be made in port or sometimes even when the vessel was at sea. Today, cruise ships are almost floating cities and waste is disposed on mainly when they dock but sometimes also in small on-board units.

Plasma arc incineration

One of the newest processes and the one which may create most refractories lining problems is incineration in plasma arc furnaces. These are usually large vertical, cylindrical pressurised vessels in which mixed waste is subjected to both pyrolysis, and as the temperature rises to complete incineration.

Relatively few of these types of unit are in operation, and some have reported severe slagging in the areas of higher temperature. One solution for the lining of this high temperature section is the use of alumina chrome spinel bricks from USA or China.

Future trends

It has to be acknowledged that refractories have both an important, and a very difficult role to play in the current and future requirements for the entire range of thermal treatment of many waste products (Fig. 10). Refractories usage in the incineration field is calculated to be about 5 kg on average for every ton of waste burnt, and is thus a substantial enduser outlet for a wide range of refractories and insulation products.

While the EU has stated that their future policy is that incineration will not grow as an option for waste disposal, it is very difficult to see how that can realistically be achieved.

Even if it is achieved, the maintenance of existing plants will continue to be key activities for refractories producers and installers many of whom have annual contracts with endusers.

In other geographic markets, such as China especially, it seems that there is enormous potential for growth from both new large plants, and ongoing maintenance of those already operational. In between, there are very many niche markets for the disposal by incineration of products which simply cannot be recycled or sent to landfill because they are hazardous from both a physical and a chemical standpoint.

Refractories engineers thus need to forge strong links to endusers, to understand and serve their local requirements better for the mutual benefit of everybody on the planet. Refractories engineers around the globe have an important role to play in the solution of some difficult problems in what appears to be a large and increasing end use for the range of refractory products.