Refractory Materials and Systems for Incineration Processes

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There is a urgent and growing need for the recycling or disposal of by-products and waste of many varied types from both domestic and industrial sources. One such solution is incineration. When carried out efficiently it is safe and cost effective but there is still considerable resistance to this technology from many sources since not all incinerators are as efficient as they should be. One of the keys to the proper operation of all of these units is the careful choice and installation of the appropriate refractories in each zone of the lining.
Operating conditions in several of the many varied designs are considered and refractories are suggested to resist the particular conditions encountered in them. Several examples of recent refractory problems which have arisen are highlighted along with the solution in each case.

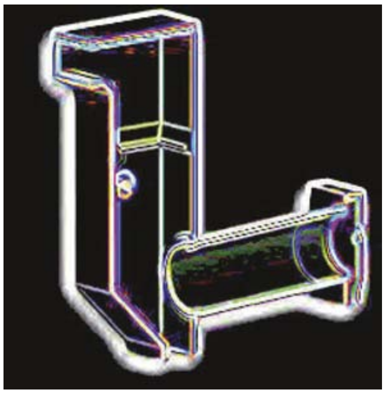

Fig. 1 **Chemical waste incinerator (Courtesy: Vesuvius)**

1 Introduction

Consumerism in the twenty first century increasingly drives manufacturing and distribution on a world wide scale to promote a better standard of living. This benefits the manufacturing personnel in companies which are often based in developing nations and the consumers who may still be largely based throughout the developed nations or in the upper echelons of the developing nations themselves. This process however in itself develops large quantities of waste for example in packaging and in the actual manufactured goods themselves when they reach the end of their life whether through changes in fashion or through becoming uneconomical to maintain or repair. Increasing emphasis is being given to recycling rather than just disposal of packaging and products although disposal by one means or another is still substantial and in some cases absolutely necessary for health and safety or other specific reasons.
It is of course also vitally necessary that some industrial by-products whether solid liquid or gas can be safely and efficiently disposed of in many manufacturing processes such as in the chemical and petrochemical and food industries.

2 Incineration

One of the major techniques used to dispose of waste materials is incineration. This involves the complete combustion or thermal oxidation of the waste product and the safe disposal of the small amounts of solid, liquid or gaseous matter, which remain after burning the initial feedstock.
Incineration disposes of the waste creating mainly water vapour and carbon dioxide although due to the diversity of feed there may sometimes be other ash, slag or gases left over as the by products of combustion which must be dealt with further to make them safe.
Incineration today is often linked with heat recovery such as in power generation from associated boiler installations. These may use fuels such as wood chips or dried sewage sludge. Incineration may also be associated with energy and cost savings as in the addition of waste products such as car and truck tyres to other fuels in industrial processes. The cement industry for example is making substantial and increasing use of secondary fuels which may be based on items such as reclaimed oil, rubber, plastic, paper, or even baled domestic waste. Some cement kilns utilise up to 90 % alternative fuels.
Legislation in some areas is driving the increased use of incineration and the much tighter standards being applied are dictating the use of more sophisticated continuous processes rather than the older batch type or semi continuous furnaces. This would be applicable for instance to hospital incinerators handling clinical waste.
Some countries already incinerate a high proportion of their domestic and industrial waste for environmental reasons while oth-

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Keywords: bricks, monolithics, high alumina, silicon carbide, shotcrete, castables, gun mixes, alkali attack

Tab. 1 Approximate percentage of waste incinerated in various developed countries

Country	Waste incinerated [%]
Switzerland	80
Japan	70
Singapore	60
Sweden	50
Holland	40
France	38
West Germany	35
Austria	20
United States	12
United Kingdom	12

Tab. 2 Chemical analysis of high-alumina phosphate-bonded brick [mass-%]

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Alkalis	P_2O_5
32,7	61,5	0,9	0,2	0,2	0,5	0,3	3,7

Tab. 3 Physical properties of high-alumina phosphate-bonded brick

Bulk density	Apparent porosity	Cold crushing strength	Abrasion loss	Spalling cycles
2,70 g/cm³	12 %	55 MN/m²	10 g	30 plus

ers are rapidly trying to catch up with the best practice available.

Switzerland has one of the highest percentage disposals at about 80 % burning about 3000 t at about 26 different municipal or private sites.

Germany has a lower percentage at 35 % but a higher tonnage at over 14 000 t being burned at over 50 sites. The UK only disposes of about 12 % of its domestic refuse by incineration. This amounts to about 10 000 t at about a dozen sites but the numbers are growing rapidly. There are currently plans to build many more units in the UK but some of these are being contested by local communities.

The raw material fed to incinerators is incredibly varied even when some attempt is made to sort it. This variation is not only from country to country but from site to site and even from hour to hour.

In the USA waste is classified into six main types by physical form and by physical attributes such as density as well as by chemistry. They also classify incineration processes by design and operation. Obviously the type of waste and the type of incinerator have a major influence on the rate at which waste can be safely and completely burned. Initial combustion of waste can vary from very slow such as with sludge or wet vegetable matter to explosive with inflammable liquids in drums and almost anything that can be imagined in between those extremes.

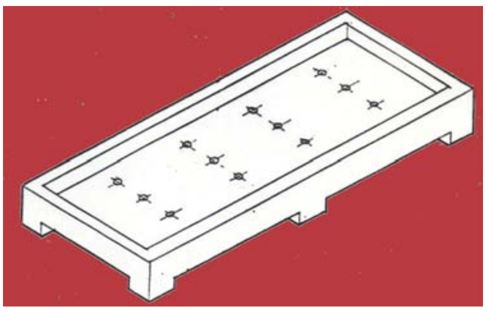

Fig. 2 Cremator base (Courtesy: Calderys)

Cremation is also a type of incineration albeit specialised and seldom discussed.

Incineration is often thought of as less demanding on refractories than other processes such as steelmaking. This is not usually the case, however, since in most other processes such as steel making there is much better process control. Even although at first sight the temperatures in incinerators may appear to be lower and the tonnages handled much less the temperature and load of the operation usually varies greatly.

3 Refractory choices

In incinerators there are design and mechanical considerations which must be taken into account when specifying refractories.

After the initial charging of waste and the resultant rise in temperature which may be rapid there is mechanical abrasion from turning the waste over or reciprocating it or causing it to be in suspension in a highly mobile fluidised bed.

Before, during and after combustion the charge can give rise to high temperature abrasion on the lining. Where slags are formed, there may also be corrosion and in high temperature gas streams with particulate matter there is a high probability of erosion. Where liquid slags or gases are cooled rapidly in the process, there can be severe thermal shock. In cooler parts of the furnace there can also be severe acid attack not only on the refractories but also on the furnace shell as well.

With most incinerators it is not a case of either or but often a case of all of these mechanisms to a different degree in different parts of the furnace at different times. It can be easily understood therefore that there is not a standard recommendation for refractories used to line incineration processes.

Conventional wisdom called for the use of dense high alumina brick wherever possible but for various reasons including the complexity of the furnace the cost and the need for fast efficient repairs ultra-low cement castables are now widely used.

Where the furnace is big enough these products can now be installed on both new and existing linings by shotcreting as well as by casting in-situ and there is increasing use of precast shapes. In cases where high alumina brick was not viable then silicon-nitride bonded silicon carbide bricks and special shapes are often specified

In waste-to-energy processes where heat recovery is important to the economics there is also a move to use products with exceptionally high thermal conductivity such as silicon-carbide castables or plastics.

Where there are extremes of high temperature and/or abrasion, corrosion or erosion then very specialised materials such as a ceramic-matrix composite in precast-block form may be necessary.

One major incinerator installation in Alaska used to burn large quantities of varied rubbish from cruise ships is constructed from large prefabricated panels of SIFCA™ because of thermal shock resulting from excessive temperature cycling from the intermittent charging and operation of the units.

4 Operational experiences

Some of the refractory success stories in the industry in the last few years include:

4.1 Secondary combustion chamber of a clinical waste incinerator

Here there was a very high and widely fluctuating temperature. The flue gases were occasionally as high as 1450 °C but contained entrained dust and slag, which caused extremely low melting point eutectics to form on the surface of the refractory. The variations in temperature gave rise to pinch spalling of the altered hot face and shelling off of the surface layer to allow the reaction to recommence.

Solution:
Very dense high-alumina phosphate-bonded brick manufactured from fired andalusite aggregate to provide a product with excellent resistance to alkali attack, thermal shock, abrasion resistance and good high temperature creep properties.

4.2 Charging areas of a multi-feed municipal waste incinerator

In this case the refractory was subjected to very high hot abrasion and moderate fluctuating temperature so that very short service lives were the norm in the charge area.

Solution:
Ceramic-matrix composite material, based on silicon carbide ceramic and melt extract 310 S grade stainless-steel fibres, were installed in the critical area. This type of product can only be supplied as precast blocks and shapes but is extremely versatile and can be treated almost like a heat-resistant steel casting, so far as its application and properties are concerned. The main advantage of this type of product however is its ability to absorb very levels of mechanical stress from impact at elevated temperature.

Chemical properties:
This material cannot be analysed in a conventional way due to the high proportion of stainless steel fibres in a refractory matrix making it a hybrid material.
This material, which is an engineered ceramic-metal mixture, cannot be tested by conventional test procedures. Its cold and hot strength characteristics are superior and quite different to other refractory materials due to the high steel fibre content within.

4.3 Heat exchange section of a large tyre-burning heat-to-energy plant

This unit was subjected to severe high temperature abrasion but had to work with a thin refractory lining to promote heat transfer. The very thin lining however was then susceptible to high wear from hot abrasion.

Solution:
Low-cement high-alumina multi-viscosity shotcrete mix was employed. This material is mixed in an integral mixer/pump with low water content and a chemical activator to make it flow easily while being pumped to the nozzle where activator causes an almost immediate set even when shot overhead onto prepared anchors .

4.4 Moving grate incinerator with domestic refuse charge

This type of unit can have either reciprocating sloping grates or roller hearths where they experience conditions giving both high hot abrasion and slag attack especially at or near the grate level.

4.5 Cement kiln firing a high proportion of alternative fuel

The difficulty in this type of application where a cement kiln is used effectively as an incinerator is that refractory wear is different and much more severe than in a conventional kiln firing either conventional solid or liquid fuel. This does not normally show up to the same extent in the burning zone of the kiln itself which normally operates around 1600 °C and where the lining has a permanent coating of cement clinker. Neither does it show up to any extent in the cement clinker product since the kiln processes between 1000 and 10 000 t/d of product

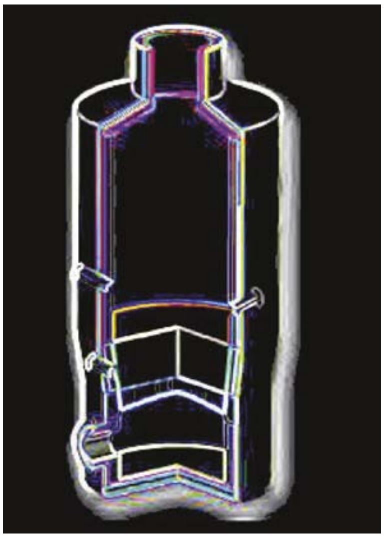

Fig. 3 Fluidised bed incinerator (Courtesy: Vesuvius)

Tab. 4 Physical properties of ceramic-matrix composites

Bulk density	Apparent porosity	Thermal expansion	Thermal conductivity	Hardness Rockwell number
3,0 g/cm³	8 %	1,0 % at 1273 K	4 W/m · K	95

Tab. 5 Chemical analysis of high-alumina low-cement multi-viscosity castable [mass-%]

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Na_2O	K_2O
25,4	70,7	0,9	1,1	0,1	1,6	0,1	0,1

Tab. 6 Physical properties of high-alumina low-cement multi-viscosity castable

H_2O to mix	Bulk density	Cold crushing strength	Modulus of rupture	Permanent linear change	Thermal conductivity
6,5 %	2,53 kg/m³	28 MN/m²	10 MN/m²	0 % at 1273 K	2,2 W/m · K

Tab. 7 Chemical analysis of phosphate-bonded high-alumina/silicon carbide ram mix [mass-%]

Al_2O_3	SiC	SiO_2	Fe_2O_3	Alkalis	P_2O_5
23	65	23,0	0,3	0,1	3,8

Tab. 8 Physical properties of phosphate-bonded high-alumina/silicon carbide ram mix [mass-%]

Bulk density	Permanent linear change	Cold crushing strength	Modulus of rupture	Thermal conductivity
2,7 g/cm³	+ 0,1 %	60 MN/m²	15 MN/m²	6,0 W/m · K

and the dwell time in the furnace is relatively short and mainly at very high temperature. The refractory problems occur mainly in the ancilliaries such as the preheater and cooler and even more so in units such as tertiary air dampers which are often in very exposed locations in the process.

The alternative fuels always contain elements and compounds damaging to refractories. There are many varied impurities but these almost always contain alkali salts and almost all of these volatilise at high temperature. They are then entrained in the gases which impinge on refractory surfaces.

The impurities in vapour form penetrate the refractory depending on its porosity and condense into liquids which attack the refractory components forming low-melting point eutectics.

This reaction is worse with refractories containing high alumina in almost any form even if the aggregate is high fired. The reaction also affects and attacks any cementitious bond in monolithics and the steel anchors or support skeletons such monolithics sometimes contain. The reaction even affects stainless steel fibres if these are present in the monolithic or precast shape causing growth and deterioration in strength of the entire unit.

Some large modern cement plants use an external incinerator to generate preheat in the process. Typical of this would be the FL Smidth HOTDISC™ unit which is in effect a small refractory monolithic-lined annular furnace burning tyres and waste.

Solutions:

In such processes it is imperative to use refractories which can best resist not only temperature but severe chemical and mechanical attack.

One solution is to use refractories with very pure synthetic aggregates such as fused magnesia grain.

Where monolithics are used these should have a pure aggregate, no or low cement bond and have maximum density with minimum apparent porosity to prevent gas penetration.

4.6 Sewage sludge incinerator

This has a feed of dewatered sewage sludge onto the top hearth of a multi hearth unit.

The sludge is progressively dried and combusted by transferring it using rotating rabble arms down through up to seven grates until all feed material is completely burnt and discharged as a small amount of inert ash which is easily and cheaply disposed of.

Solution:

These hearths which were traditionally built from firebrick in an inverted dome shape are being replaced with high-alumina low-cement castable which is either cast in-situ 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 means that the shapes can be cast in controlled conditions and don't need such lengthy commissioning.

5 Conclusion

It would seem that the main conclusion to be reached, is that the only thing that is the same about most incinerators is that they are all different in operation, although similar in being subjected to the same fundamental problems, which cause refractory deterioration.

This means that refractory linings must be chosen for each individual zone of each unit with due regard to the fact that premium properties will inevitably be required to withstand what is almost always extremely arduous operating conditions in these furnaces. This requires both a knowledge of the process and the refractories proposed.

6 Facit

For application in
- Municipal incineration
- Clinical waste incineration
- Sewage sludge incineration
- Chemical waste incineration
- Wood waste incineration
- By-product gas oxidation:

Refractories are the key !