ABSTRACT

With the ever increasing generation of hazardous wastes and recent RCRA regulations changing the country's hazardous waste management philosophy, incineration has become a very viable and efficient alternative to burying and recycling. Since incineration systems such as the rotary kiln and liquid injection units seem to be the most popular and promising designs, the reaction between the refractory lining and the waste system has taken on new importance. Alkalies introduced as salts and halides from halogenated hydrocarbons work in conjunction with higher efficiency temperatures to put new strains on linings. The basic effects of these detrimental compounds on various refractories have been investigated through actual incinerator slag tests and the results of these tests are discussed in order to determine a general rule of thumb on selecting refractory materials.

BACKGROUND

When the Environmental Protection Agency's Resource Conservation and Recovery Act Regulation (RCRA) became effective in November of 1980, it had an impact on refractories, as well as the environment.

RCRA established "cradle to grave" standards for industrial wastes considered by regulation to be hazardous, requiring more thorough methods of disposal and disposal monitoring. All areas of hazardous waste disposal, from chemical treatment to landfill dumping, are covered in RCRA.

Hazardous waste management is a complex issue where no single process can be applied to all waste streams. The following are several options for managing waste:

1. Wastes can be recycled.
2. They can be treated and recycled.
3. Wastes can be treated and disposed.

There are certain hazardous materials that are hazardous simply because of the structure of their molecules rather than the properties of the elements contained. For these types of hazardous materials, high temperature incineration is the best means of disposal. Carbon dioxide, water vapor and inert ash are usually all that remain after incineration. Because of these factors, incineration has become the fastest growing method of disposal in the 1980's. According to the EPA, there will be a 55 percent increase in the amount of wastes handled through incineration in 1982 and in 1983 a 44 percent increase is projected.

In contrast, the amount of hazardous wastes disposed of in landfills is expected to decrease by 9 percent in 1982 and chemical treatment of industrial wastes should rise at a rate of only half that projected for incineration.

HIGHER STANDARDS, HIGHER TEMPERATURES

As RCRA tightens the regulations on traditional dumping and burying practices, waste generators and handlers look to incineration as a complete and cost-effective disposal practice, a trend already experienced in Europe. However, RCRA has in-
creased the efficiency requirements for hazardous waste incineration. The RCRA performance criteria for industrial incineration require that all incinerators burning hazardous wastes achieve a destruction and removal efficiency of 99.99 percent. For incinerator operators this usually means higher burning temperatures and longer burn times.

Although not required, the EPA suggests a minimum retention time of 2 sec at 1,830 F (1,000 C) combustion temperature, or 2,200 F (1,205 C) if the wastes contain halogens. Retention time is the amount of time that the hazardous waste molecules must be maintained at these temperatures to break down and thereby achieve the proper combustion efficiency. Until now, temperatures of 1,500 F - 1,700 F (816 C - 927 C) would have been considered sufficient for hazardous waste incineration.

Thus, many incinerator operators will increase efficiency by the cranking-up of furnace temperatures beyond limits previously considered sufficient — a move that hits home with refractory users because of the new strains put on linings used in incinerators. Incineration of hazardous wastes has always been a complex matter when it comes to refractories, because the waste stream contains compounds which can be very destructive. And with the higher temperature needs required by RCRA, some refractories once thought adequate for an incinerator will have to be replaced by others. In certain cases, incinerator linings just won’t hold up as long as could previously be expected. But it’s a sure bet that the increasing demands for environmentally safe disposal through incineration will bring new and tougher demands for refractory performance.

TYPES OF INCINERATORS

Generally speaking, there are five major types of incineration processes in use today, the most common being the rotary kiln and liquid injection methods (Sketch 1) [1]. Rotary kilns have the advantage of being able to burn most forms of toxic organics, as well as the barrels which contain them. Rotary kilns generally have secondary chambers which burn gases at higher temperatures than the primary chambers. Operating temperatures in rotary kilns have ranged from 1,500 F - 3,000 F (816 F - 1,650 C) and these systems can handle most forms of toxic organics.

Liquid injection involves a vertical or horizontal vessel with wastes atomized and sprayed through nozzles into the combustion chamber. Injection systems are limited to use with pumpable liquids and slurries and their operating temperatures range from 1,200 F - 3,000 F (649 C -1,650 C).

Other methods of industrial incineration are: pyrolysis, the thermal decomposition of a substance in the absence of oxygen; multiple hearth, a system of vertically stacked hearths used mainly on sewage sludge; and fluidized bed, where wastes are injected into a hot agitated bed of inert granular particles.

Lastly, a version of incineration that is recently gaining favor in the U.S. after its introduction eleven years ago in Europe is waste incineration at sea. This method of incineration, involving a fleet of vessels equipped with rotary or liquid injection incinerators, could be a vital part of tomorrow’s waste management solution.

A major reason “at sea” incineration could be advantageous is its handling of the vapor form of hydrochloric acid. On land, incinerators require scrubbers to remove the HCl, which readily assumes its liquid form. However, the ocean seems to be capable of breaking down the problem gas without environmental side effects, thus eliminating the need for troublesome scrubbers [2].
All types of incineration processes are covered by the RCRA regulations, which only complicate the already complex refractory-waste stream relationship. As efficiency specifications increase in all types of incinerator systems, so will the demand on refractories.

TESTING AND EVALUATION
ALKALIES AND HALIDES: DESTRUCTIVE TO REFRACTORIES

At increased operating temperatures, the waste put into an industrial incinerator can be especially destructive to the lining. Two destructive components found in industrial wastes are alkalies and halides.

Alkalies can have a detrimental effect when they react with fire-clay and high alumina refractories. The alkalies flux the alumina-silica (40-55 percent $\text{Al}_2\text{O}_3$) system, causing glass formation on the surface of the refractory. At low temperatures, this can be beneficial since the glazing seals the refractory surface (Fig. 1). However, if the temperature is raised higher, the glass could become fluid and drain from the hot face.
If temperature conditions are such that a glass densified zone forms, rapid cooling can cause spalling of the altered portion of the brick. This phenomenon results from structural stresses set up by the differential rates of thermal expansion between the unaltered refractory and densified zone (Fig. 2). Therefore, if the incinerator operator attempts to comply with RCRA by increasing the temperature, the refractory may need to be upgraded. However, alkali reactions may still occur. Compositions higher in Al₂O₃ can show both glass formation and the presence of expansive alkali-alumina-silica phases. If potash is present, the phases typically observed are leucite (K₂O·Al₂O₃·4SiO₂) and kalsilite (K₂O·Al₂O₃·2SiO₂). If soda is present, the expansive phase typically observed is nepheline (Na₂O·Al₂O₃·2SiO₂). Bricks with greater than 70 percent alumina normally contain free alumina (corundum) which can also react to form an expansive alkali-alumina phase. The presence of these expansive phases results in disruption of the brick structure and loss of strength (Fig. 3).

Thus, reaction can occur with all types of refractory materials, but certain brick classes have better resistance to reaction at certain temperatures. This has also been observed by laboratory slag testing (Fig. 4). In cyclic alkali cube testing at 2,200 °F (1,205 °C), alumina-silica compositions in the 40-55 percent Al₂O₃ range show a glazing of the surface. These samples appear relatively unaffected after six test cycles. As we increase alumina content, materials in the 55-65 percent range show both glazing and minor cracking after six test cycles (Fig. 5). In the 70 percent alumina range, severe deterioration was observed after three cycles (Fig. 6).
Discussions concerning higher temperature applications can be found in the conclusion and summary section.

Another group of compounds found in waste streams harmful to refractories are the halides: Chlorides, fluorides, and related compounds. Of
these, the effects of chlorine and chloride are probably best understood.

Chlorine reaction with silica and alumina is a severe problem. Chlorine reacts with these oxides to form volatile chlorides. The removal of silica and alumina will increase the porosity and reduce the strength of the refractory. An example of this can be seen by examining two high alumina compositions before and after exposure to a chlorine-bearing atmosphere. A 99 percent $\text{Al}_2\text{O}_3$ composition showed loss of the fine matrix bond phase (Fig. 7). A mullite composition shows disruption of matrix and coarser fractions due to removal of silica via volatile $\text{SiCl}_4$ formation (Fig. 8).

FIG. 7 99 PERCENT $\text{Al}_2\text{O}_3$ BEFORE AND AFTER CHLORINE ATTACK (TWO PHOTOS)
These volatile chlorides may flow out of the incinerator and condense downstream where they have been known to cause blockages in cooler areas such as gas cleaning equipment or waste heat boilers.

When free chlorides are present with alkali, these compounds may condense within the lining forming expansive alkali-chloride phases. The presence of these phases can result in cracking of the refractory (Fig. 9). Chlorine gas will also react with the bonding phase in castables. If the material is calcium aluminate cement bonded, calcium chloride is formed. If the material is sodium silicate bonded, sodium chloride is formed. The presence of these phases reduces the strength of the castable, plus these phases are water soluble. Thus, in the presence of water or high humidity conditions, a complete removal of the bond is possible (Fig. 10-11).

The effect of fluorine is similar to chlorine. Fluorine has been found to act as a flux in glassy silicates, but chlorine has not, indicating that fluorine is more active than chlorine.

Like alkalies, halides can be extremely corrosive in contact with most refractories. Most problems usually begin at lower temperatures downstream or at the backside of the lining where halides can condense. Depending upon the temperature, a dense high-fired superduty brick (40-50 percent Al₂O₃) or a dense 60 percent Al₂O₃ brick lining with low porosity and a minimum of excess Al₂O₃ or SiO₂ will usually keep reactions to a minimum.
INCINERATOR SLAG TESTS

One way of determining which incinerator lining materials should be used is to perform slag tests using a slag from an actual incinerator operation. The following is a compilation of four slags recently evaluated and tested.

1. The first example is a case in which a company burned hazardous waste in a rotary kiln. Barrels containing hazardous wastes were dumped into the kiln which had been running successfully with a superduty brick at approximately 1,800 F (983 C). With the new RCRA regulations, the operating temperatures were increased to the 2,370 F-2,740 F (1,300 C-1,506 C) range, and both a superduty brick and a 70 percent composition proved unsuitable. Analysis showed that the slag, Slag “A,” consisted of high concentrations of iron oxide and silica with minor alumina and lime (Fig. 12). At these higher temperatures, these oxides caused fluxing of the alumina silica bond in a 70 percent \( \text{Al}_2\text{O}_3 \) system (Fig. 13) resulting in corundum and anorthite \( (\text{CaO}.\text{Al}_2\text{O}_3.2\text{SiO}_2) \) in a low melting Fe-Si-Ca-Al glass. In an effort to find a more suitable refractory lining material at these high temperatures, cup slag tests were performed at 2,910 F.
2. Another series of slag tests were performed using a liquid injection incinerator slag, Slag "B," rich in phosphorous pentoxide and soda with minor alumina (Fig. 12). Testing consisted of cup slag evaluations at the operating temperature of 2,400°F (1,317°C) using 100 g of slag per cup. Testing indicated that a fireclay composition (42 percent $\text{Al}_2\text{O}_3$) showed glass formation and fluxing (Fig. 15). A 60 percent $\text{Al}_2\text{O}_3$ composition showed retention of much of the slag within the cup with only limited reaction about the cup exterior (Fig. 16). A direct bonded magnesite-chrome composition was weak and friable after testing due to the reaction of the alkali with the chromite spinel which disrupted the direct bonding (Fig. 17). A 100 percent magnesite composition showed no reaction with the slag but the slag had penetrated the sample and filled the porosity (Fig. 18).

3. A third series of tests involved a liquid injection slag, Slag "C," containing significant concentrations of soda, alumina, silica, and phosphorous pentoxide. Note the concentrations of soda and phosphorous pentoxide approximate those of "Slag B." However, the quantities of alumina and silica are much greater in Slag "C" (Fig. 12).

Testing consisted of cup slag tests at both 2,200°F (1,205°C) and 2,600°F (1,428°C) on the high alumina and basic brands already discussed and drip slag tests at 2,650°F (1,456°C) on selected brands.

After the 2,200°F (1,205°C) tests, all samples showed trace to no penetration or alteration. How-
FIG. 14a CUP SLAG TESTS USING SLAG "A" WITH 85 PERCENT $\text{Al}_2\text{O}_3$ PHOSPHATE BONDED BRICK

FIG. 14b CUP SLAG TESTS USING SLAG "A" WITH A 90 PERCENT MULLITE BONDED $\text{Al}_2\text{O}_3$ COMPOSITION (LEFT) AND AN ALUMINA CHROME COMPOSITION (RIGHT)

FIG. 15 CUP SLAG TESTS USING SLAG "B" WITH 42 PERCENT $\text{Al}_2\text{O}_3$

FIG. 16 CUP SLAG TEST USING SLAG "B" WITH 60 PERCENT $\text{Al}_2\text{O}_3$
ever, the phosphate bonded 85 percent $\text{Al}_2\text{O}_3$ composition exhibited slight penetration (Figs. 19-22).

After the 2,600 F (1,428 C) cup slag tests, the phosphate bonded 85 percent $\text{Al}_2\text{O}_3$ compositions again showed the most severe alteration. The fireclay and high alumina compositions showed a glazing of the slag cup with no significant penetration (Figs. 23-25).

The 100 percent magnesite composition again showed no reaction with the slag. However, the slag was absorbed into the brick structure (Fig. 26).

Mineralogical examination revealed that all the fireclay and high alumina samples showed the same type of alteration mechanism, that is, solution of the bonding matrix and coarser fractions resulting in altered alumina-silica calcines and corundum in a glassy Na-P-Al-Si matrix. The important difference was the rate at which the reactions occurred. The phosphate bonded compositions exhibited the poorest resistance. The 60-90 percent $\text{Al}_2\text{O}_3$ materials exhibited alteration only at the slag-brick interface (Figs. 27, 28). As expected at 2,600 F (1,428 C) slightly greater quantities of glass were detected in the fireclay sample (Fig. 29).

Five compositions were selected for the more dynamic drip slag test. From the cup slag tests, we know that lower melting glassy phases were formed, but these phases just collected within the cups. The viscosity of this glass is extremely important in relation to how quickly the refractory can be eroded away. The drip slag tests consisted of dripping 1.50 kg of slag on to each test sample and measuring the amount of erosion in cubic meters.

Results again showed that two 85 percent $\text{Al}_2\text{O}_3$ phosphate bonded brick compositions were the most altered while the 90 percent alumina compo-
FIG. 20 CUP SLAG TEST USING SLAG "C" AT 2,200 °F (1,205 °C) 85 PERCENT PHOSPHATE BONDED $\text{Al}_2\text{O}_3$ DRIED (LEFT) AND 60 PERCENT $\text{Al}_2\text{O}_3$ (RIGHT)

FIG. 21 CUP SLAG TEST USING SLAG "C" AT 2,200 °F (1,205 °C) 60 DOMESTIC $\text{Al}_2\text{O}_3$ (LEFT) AND 90 PERCENT MULLITE BONDED $\text{Al}_2\text{O}_3$ (RIGHT)

FIG. 22 CUP SLAG TEST USING SLAG "C" AT 2,200 °F (1,205 °C) HARD BURNED SUPER DUTY 43 PERCENT $\text{Al}_2\text{O}_3$ (LEFT) AND 100 PERCENT $\text{MgO}$ (RIGHT)
position showed only minimal erosion at these elevated temperatures (Figs. 30, 31). The 60 percent $\text{Al}_2\text{O}_3$ compositions were glazed and showed trace to no erosion (Figs. 32, 33, 34).

4. The last series of slag tests were performed with an iron oxide-silica-phosphorous pentoxide rich slag, Slag “D,” containing only minor soda. As with Slag “A,” Slag “D” represents a rotary kiln
FIG. 26 CUP SLAG TESTS USING SLAG "C" AT 2,600 F (1,428 C) HARD BURNED SUPER DUTY 43 Al₂O₃ (LEFT) AND 100 PERCENT MgO (RIGHT)

FIG. 27 MINERALOGICAL EXAMINATION OF 85 PERCENT PHOSPHATE BONDED Al₂O₃ (UNUSED AND ALTERED) AFTER SLAG TEST WITH SLAG "C" AT 2,600 F (1,428 C)

2. Na - P - Al - Si - Ca - Fe glass

5. void
type operation where barrels of waste are incinerated. However, the quantities of phosphorous pentoxide and soda are greater in Slag "D".

Both cup and drip slag tests were performed on a fireclay composition (42 percent \( \text{Al}_2\text{O}_3 \)) and two 60 percent \( \text{Al}_2\text{O}_3 \) compositions.

The cup tests were run at 2,375 F (1,303 C) with a 24-hr hold using 0.1 kg of slag per cup. Microscopic examination revealed that an alteration occurred in all compositions similar to that previously described: solution of the bonding matrix and coarser fractions resulting in altered calcines in a glassy matrix. Significantly greater slag penetration was evident with the fireclay composition than with the 60 percent \( \text{Al}_2\text{O}_3 \) brick at these temperatures (Fig. 35).

The drip slag tests were run at 2,400 F (1,317 C) using 1.200 kg of slag per sample. Greater penetration and erosion was again evident with the hard burned fireclay composition (Fig. 36).

To further identify possible reasons for the difference in slag resistance of the three brands, additional tests were run on each sample. Physical properties showed that the 60 percent \( \text{Al}_2\text{O}_3 \) compositions had a finer pore size distribution and a lower permeability than the fireclay material, even though the apparent porosity of the 60 percent \( \text{Al}_2\text{O}_3 \) composition is higher than the hard burned fireclay. Microscopic examination of the unused samples also revealed that the 60 percent compositions had a more continuous interlock mullite crystallite network and lower quantities of glass than the fireclay.

FIG. 28 MINERALOGICAL EXAMINATION OF 60 PERCENT DOMESTIC \( \text{Al}_2\text{O}_3 \) (UNUSED AND ALTERED) AFTER SLAG TEST WITH SLAG "C" AT 2,600 F (1,428 C)
FIG. 29 MINERALOGICAL EXAMINATION OF 43 PERCENT Al₂O₃ HARD BURNED BRICK (UNUSED AND ALTERED) AFTER SLAG TEST WITH SLAG "C" AT 2,600 F (1,428 C)

FIG. 30 DRIP SLAG TESTS AT 2,600 F (1,428 C) WITH SLAG "C" 85 PERCENT PHOSPHATE BONDED Al₂O₃ FIRED

FIG. 31 DRIP SLAG TESTS AT 2,600 F (1,428 C) WITH SLAG "C" 85 PERCENT PHOSPHATE BONDED Al₂O₃ DRIED
brick. These properties would minimize slag penetration and lengthen service life at these temperatures (Fig. 37).

CONCLUSIONS AND SUMMARY

HOW TO CHOOSE AN INCINERATOR LINING

An example of how RCRA impacts on refractories is the hypothetical case of a chemical waste incinerator using a superduty brick. Before the EPA regulations were enacted, it probably would have been run between 1,500 F (816 C) and 1,700 F (927 C) and superduty would work extremely well in the presence of chlorinated hydrocarbons and alkalies. But as the temperature is raised to meet the RCRA efficiency level, problems could occur. At the higher temperatures the alkalies could flux the brick, causing it to become soft and melt. If high alumina brick were substituted for superduty, expansive reactions could develop, but service life would be longer. If the incinerator temperature and salt content is extremely high, an inert basic brick would probably be tried if thermal cycling, expansion and moisture problems could be accommodated.

As the above situation illustrates, the following two variables should be taken into consideration while choosing a lining:

<table>
<thead>
<tr>
<th></th>
<th>Phosphate Bonded High Alumina (fired)</th>
<th>Phosphate Bonded High Alumina (Dried)</th>
<th>Phosphate Bonded High Alumina (Dried)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60 percent Al2O3</td>
<td>60 percent Al2O3</td>
<td>90 percent Al2O3</td>
</tr>
<tr>
<td>Drip Slag Test at 2,650 F (1,456 C) Using 1,500 kg of Synthetic Slag</td>
<td>4.1 x 10^-5</td>
<td>Trace</td>
<td>7.9 x 10^-5</td>
</tr>
</tbody>
</table>

Volume Eroded, m³

FIG. 32 DRIP SLAG TESTS AT 2,600 F (1,428 C) WITH SLAG “C” 90 PERCENT MULLITE BONDED Al2O3

FIG. 33 DRIP SLAG TESTS AT 2,600 F (1,428 C) WITH SLAG “C” 60 PERCENT Al2O3

FIG. 34 SLAG TEST RESULTS

FIG. 35 CUP SLAG TESTS AT 2,375 F (1,303 C) WITH SLAG “D” (FROM LEFT TO RIGHT: 60 PERCENT Al2O3, 43 PERCENT Al2O3, 60 PERCENT Al2O3)
FIG. 36  DRIP SLAG TESTS AT 2,400 F (1,317 C) WITH SLAG “D”  
(SEE PHOTOS FOR IDENTIFICATION)
1. Maximum operating temperature of the furnace (RCRA).

2. Chemical analysis of the feed.

In general, a rule of thumb in selecting hazardous waste incineration refractories is as follows: Let the temperature dictate the $\text{Al}_2\text{O}_3$ content of the lining. For lower temperature applications, lower $\text{Al}_2\text{O}_3$ materials generally lengthen service life. However, as the temperature increases, the $\text{Al}_2\text{O}_3$ content of the lining should also increase. The rule of thumb is meant to accommodate the incineration of halide and alkali bearing compounds in the following specific units.

**ROTORY KILN SYSTEMS**

As shown in the analysis of Slags “A” and “D,” the waste stream can contain high quantities of $\text{Fe}_2\text{O}_3$ from the drums, alkalies from the salt wastes, halides, and phosphorous pentoxide. At operating temperatures in the 1,800°F (983°C) range, U.S. and European research and experience indicates that a high fired superduty fireclay should minimize reactions and maximize service life [3, 4]. At these low temperatures, the excess alumina in a higher alumina material could combine with the alkalies and halides to form destructive, expansive reactions.

However, as the temperature in the kiln increases to the 2,100 F-2,500 F (1,150 C-1,372 C) range, the fireclay can be fluxed by the alkalies and damaged by the increased reactiveness of the $\text{Fe}_2\text{O}_3$. As illustrated by tests with Slag “D,” brick linings in the 60 to 70 percent $\text{Al}_2\text{O}_3$ range have been a cost effective approach under these temperature situations. Yet, temperatures approaching the 2,700 F-2,900 F (1,483 C-1,595 C) range should substantially shorten the life span of a 70 percent $\text{Al}_2\text{O}_3$ kiln lining. As shown under Slag “A,” linings of higher $\text{Al}_2\text{O}_3$ content should increase service life. However, a solid solution bonded alumina-chromic oxide composition was shown to minimize the reaction mechanism of the $\text{Fe}_2\text{O}_3$ at these temperatures.

The secondary chamber of the rotary kiln system can be exposed to similar temperatures and contaminants. Therefore, the same rule of thumb concerning temperature and alkali/halide reactions would apply. However, the secondary chamber will not be exposed to high quantities of $\text{Fe}_2\text{O}_3$, negating the need for the alumina-chromic oxide material at very high temperatures.

The cooler areas of the system will probably require acid resistant refractory materials because of...
acid condensation. Experts on acid resistant masonry should be consulted.

LIQUID INJECTION SYSTEMS

As shown in the analysis of Slags “B” and “C,” the quantities of alkalies introduced in the liquid units are generally much higher than those introduced in rotary systems. Hence, the refractory will be subject to very destructive conditions as the temperature increases.

In general, the same rule of thumb should apply to most refractory selections in liquid units. At low temperature in the 1,800 F-2,000 F (983 C-1,094 C) range, high fired superduty fireclay materials should maximize lining life. Along with the 2,200 F (1,205 C) tests with Slag “C,” both U.S. and European researchers have performed alkali tests under 2,000 F (1,094 C) and found that fireclay materials with 40-50 percent \( \text{Al}_2\text{O}_3 \) and less than 15 percent porosity show excellent resistance against alkali attack [4]. At these temperature, increased \( \text{Al}_2\text{O}_3 \) content does not seem to increase service life.

However, operating temperatures of 2,200 F - 2,500 F (1,205 C - 1,372 C) will cause increased reaction at the hot face, resulting in the fluxing of the fireclay. Research has shown that a 60 percent \( \text{Al}_2\text{O}_3 \) brick should maximize life in the units with slags similar to Slags “B” and “C”. Higher \( \text{Al}_2\text{O}_3 \) materials and pure mullite composition do not decrease reactions at these temperatures. In fact, the higher \( \text{Al}_2\text{O}_3 \) materials could develop expansive reactions and crack prematurely.

In liquid units that operate in the range of 2,500 F - 2,800 F (1,372 C - 1,539 C) the 60 \( \text{Al}_2\text{O}_3 \) materials are sometimes fluxed. Experience shows that a high purity 90 percent \( \text{Al}_2\text{O}_3 \) brick minimizes reactions at these high temperatures. This observation concurs with the 2,600 F (1,428 C) drip slag tests with Slag “C”.

PRECAUTIONS

Basic Brick

In tests with Slags “B” and “C,” magnesite chrome and magnesite brick show little or no reaction with alkali/halide slags due to the chemical inertness of the brick composition. Yet, the slag will penetrate the basic brick, possibly forming a spalling situation due to differences in thermal expansion. In very high temperature units where excess alkali attack is a problem, basic brick could be an alternative. However, the design must accommodate expansion and the brick’s tendency to hydrate when exposed to moisture.

Phosphate Bonded \( \text{Al}_2\text{O}_3 \) Brick

During tests with Slags “A” and “C,” 85 percent \( \text{Al}_2\text{O}_3 \) phosphate bonded brick compositions showed a higher degree of reaction than the 90 percent \( \text{Al}_2\text{O}_3 \) high purity mullite bonded brick. Whether the phosphate bonded bricks were fired or merely dried, the phosphate additions appear to act as a flux, increasing the alkali-slag reaction. Thus, the higher purity 90 percent \( \text{Al}_2\text{O}_3 \) mullite bonded brick should be a better choice in areas of rotary or injection systems that experience temperatures exceeding 2,500 F. Experience in the U.S. tends to confirm this approach.

Monolithic Materials

In most cases, because the ceramic matrices of pressed and fired brick are generally more dense and less porous, brick resist alkali reactions better than castables and plastics. Research has shown that the ceramic bond in fired refractories is less susceptible to attack by alkalies and chlorides than the phosphate, cement or clay bonds in monoliths. When monoliths must be used, however, there are criteria for choosing the material with the highest resistance to attack. Some fireclay based castables have additions to form glasses which help seal the surface against further attack. These will be effective at the lower temperature ranges (1,800 F - 2,200 F (1,983 C - 1,205 C) where glasses are very viscous. In most cases phosphate bonded plastics should be avoided for much the same reasons as were discussed for brick, i.e., the phosphate could act as an internal fluxing agent speeding the attack of alkalies. In limited tests, clay bonded plastics have performed better in resisting alkalies in the 1,800 F - 2,400 F (983 C - 1,317 C) range because, as was discussed earlier, a glassy seal forms at the surface, halting further penetration. In this temperature range, the more resistant clay bonded plastics and calcium aluminate bonded castables have \( \text{Al}_2\text{O}_3 \) contents between 40 and 60 percent.

Chlorides, as was discussed previously, are extremely detrimental to all types of plastics and castables. If monoliths must be used, plastics should perform better than castables. Chlorides will attack the calcium-alumina bond in the cement forming calcium chloride salts which are soluble in water. The high alumina (70-99 percent) plastics and castables should be avoided because of chloride reactions with free corundum (present in most high
alumina refractories). The plastics in the 40-60 percent alumina range, because of higher densities and finer pore size distribution, should give better service than most castables.

Viscosity

Although temperature and waste chemistry are the most critical furnace variables, viscosity of the waste slag at temperature is very important. An alkali-laden waste with a low viscosity will move quickly across the face of the refractory, maximizing wear by washing away the reacted material and the mortar. In contrast, a sticky viscous slag will move slowly across the refractory face, enabling some refractory brick to form a protective coating and minimize wear. In most cases, the incinerator operator should attempt to strike a balance between a very viscous slag that could clog the unit and a flowing slag stream that shortens refractory life.

Design

The selection of the refractory based on temperature and waste chemistry is the most important component of a successful refractory lining. Usually, alkali attack from salt wastes is the most destructive reaction that limits service life. A brick lining selected according to the above rule of thumb should maximize performance. In most cases, the brick selected to combat alkali reactions will also minimize damage from halides.

Thermal shock, expansion allowance, mortar usage, installation, thermal gradient and overall brick configuration are also important variables and should be discussed with refractory experts.

REFERENCES


Key Words
Efficiency
Hazardous
High Temperature
Incineration
Refractory
Rotary Kiln
Slag