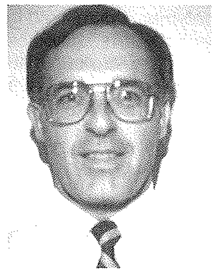

From design to application, factors have an influence on refractory linings, and it must be ensured that all concerned know what they are dealing with. In the following, a reputed refractories expert enumerates the problems and areas of ignorance that can make the situation very expensive – right on up to catastrophic collapse. The author, C.E. Semler (50), received his Ph.D. from Ohio State University in 1968. After being with Monsanto and Harbison-Walker Refractories C. for six years, he joined the faculty at his alma mater, teaching and serving as the Director of the Refractories Research Center. In addition to being active in many refractories associations – Fellow of the American Ceramics Society, Chairman of the Refractories Committee of ASTM and the American Foundryman's Society, Member of the International Executive Board of UNITECR – today he is an Adjunct Professor at Ohio State University and a Consultant at Semler Materials Services.

Overview of Refractory Problems in Industry

C.E. Semler,* USA

Abstract

Refractories are the "Backbone of Industry." Despite their great importance, refractories are frequently misunderstood, overlooked, and/or abused. The results can be extremely disruptive, costly, and even tragic. This paper defines seven main reasons for refractories problems in industry, and notes seven other contributing factors. Many practical examples are included. Based on an improved understanding of the reasons for refractories problems, as well as a thorough review of all related factors, it is possible to reduce or eliminate unnecessary and unexpected major expenses.

Interceram **40** (1991) [7]

1 Introduction

Refractories are the "Backbone of Industry" because they are the basis for profitable operation of virtually all thermal and chemical processes worldwide. However, despite their tremendous importance, refractories are frequently overlooked, misunderstood, and abused, bringing about associated losses in time, production, and money, most of which are completely unnecessary and avoidable. Based on common sense and practical, proven guidelines, it is possible to minimize or eliminate most refractory-related problems and avoid the unnecessary expenses, which in the worst cases can involve lost production, plant closure, injury, and death. It is especially disheartening to see problems, major expenses, and tragic accidents that could have been easily avoided. But for a variety of reasons, refractory oversight and misuse continues, resulting in ongoing difficulties and expenses for refractory users and manufacturers alike.

To address the problems associated with refractories, it is first necessary to recognize the main factors that are involved. The purpose of this paper is to define the main reasons why refractory problems occur, based on the writer's in-plant experience as an independent refractories analyst in various industries for over 16 years. As a practical overview, this paper presents information that is general in scope and not specific to any industry. The intent is to provide meaningful background for readers in various industries and to help promote greater understanding and concern for refractories. Numerous examples of actual industrial problems are given to illustrate the kind of oversights and abuses that occur, with hope that the readers might relate to a case mentioned and take corrective action(s).

2 Reasons for Refractory Problems

Refractory users don't always recognize that their actions and oversights, as well as those of their contractors, distributors, and others, can directly affect refractory performance. So it is common when a problem that might be related to the refractory lining occurs in an industrial furnace/reactor, the first claim is usually, "the refractory was bad." However, in-plant inspection and analysis experience has shown that furnace/reactor refractory problems are commonly the result of a combination of several factors and not just one factor. Many times, an unlikely sequence of actions or events will occur creating an unexpected worst-case situation. In some cases, the quality/properties of the refractory might contribute to the problem, but it is also possible that a perfectly good refractory can be degraded prematurely because of a combination of other factors and appear to be poor quality, due to no fault of the manufacturer. So the evaluation of any refractory problem should consider the full range of possible factors to reach the correct conclusions and permit meaningful recommendations.

A refractory-lined furnace/reactor must be considered as a system in which there are numerous interacting physical and chemical effects that may be ongoing, progressive, cyclic, etc., which will definitely control the refractory performance. In addition, there are numerous factors prior to the refractory's being exposed in the furnace/reactor, which directly affect refractory performance. The seven general factors that most commonly contribute to refractory problems are listed below, followed by a discussion of each:

○ Design of the system and the refractory lining
○ Refractory selection or specification
○ Refractory quality and/or properties
○ Installation of the refractory lining
○ Curing, startup, and maintenance of the refractory lining
○ Operation of the system
○ Chemical characteristics of the system/process.

As mentioned above, if these factors are not known or are overlooked, there can be unexpected, costly, and tragic consequences. Refractories can be the controlling factor in the success or failure of a furnace/reactor campaign, the safe operation of a system, and more broadly, in the profitable operation of a plant.

2.1 Design of the System and the Refractory Lining

The structural design of a furnace/reactor has a direct effect on the refractory lining inside, and can cause various detrimental effects, such as cracking, spalling, chemical attack, erosion/abrasion, collapse, etc. A few of the significant structural considerations are brick size/shape, pattern of brick installation, type of metal shell, irregular and/or angular configurations, sharp radii, restriction of or allowance for thermal expansion, internal ledges, and anchor type/layout.

The design of the refractory lining for a furnace/reactor should be developed based on full knowledge of the different conditions that are active, e.g., temperature, pressure, slag/chemical attack, thermal shock, abrasion, impact, molten metal contact, oxygen injection, presence of steam, and rotation or tipping of the unit, to name a few. But frequently the complete information needed to properly design a refractory lining is not available. For example, the conditions in a system may vary widely during operation, and if the refractory user(s) does not know or accurately measure the conditions at all stages of the use cycle, essential information may be lacking. In the absence of critical information, wrong decisions and selections can be made. Direct interaction of a refractory user with the manufacturer(s) or an independent consultant to fully evaluate a system can result in practical and economic improvements in lining design/performance.

Designing a refractory lining is not yet an exact science, and commonly there are practical concerns, compromises, and experience-based judgements involved. There are many variables that impact the performance of refractories, and frequently the specific experience or test data are not available to confirm a refractory selection. Commonly it is not practical to generate the specific information needed because of time and cost factors. There is increasing use of computer techniques to custom design refractory linings based on the specific needs and use conditions, but the computerized design work is only as good as the input data and the experience of the analyst. Especially needed is an ongoing program to compile and/or determine valid high-temperature properties, that are internally consistent and comparable and to advance the capabilities of computerized lining design. Also, refractory product data sheets should be upgraded to always include the property data needed for lining design by either manual or computerized techniques.

The goal in refractory lining design is to use the proper materials in each of the different wear regions of a furnace/reactor (e.g., slag line, impact pad, bottom, pour spout, vapor zone, etc.), so the whole lining will wear at the same rate. By properly "zoning" a refractory lining, it should be possible to meet the desired cost, performance, scheduling, maintenance, and other criteria that are important.

Several examples of problems associated with design factors follow:

○ Improper design of the anchor system for the skid rails and sidewalls in a steel reheat furnace caused early cracking and collapse. The condition of the skid rails was worsened by inadequate cleaning of the steel ingots
○ An unstable refractory lining with an insulating castable on the hot side backed by fiber board, was used in a new reactor where several high-velocity streams of sodium chemicals caused quick erosion, cracking, and failure within weeks. The initial lining had to be torn out and replaced with a different lining, which was a major unplanned expense.
○ The design of the well block/bottom nozzle in a 250 t ladle, included a straight-through mortar joint, which contributed to a bottom runout of molten steel, with significant equipment damage and costly downtime
○ The design of stainless steel offgas ducts for an incinerator system upgrade, based on previous chemical conditions which did not exist in the new unit, caused cracking and collapse of the refractory lining inside
○ Reheat furnace roof sections collapsed because the refractory design allowed overheating and failure of metal clamps supporting the anchor brick
○ The design of the nozzle/refractory interface in the bottom of an induction furnace allowed 3000 °F molten steel to easily reach the 2600 °F backup insulation. The insulation layer was completely penetrated and melted, and a bottom runout of molten steel occurred after 12 h of operation.

2.2 Refractory Selection or Specification

Inherent in a successful refractory lining design is the use of the correct, or most appropriate, refractory products. The selection of an inadequate or wrong refractory can be the basis for major difficulties, either immediately or later in a campaign. There are many examples of the wrong refractory being used in a furnace/reactor, resulting in problems due to physical and/or chemical deterioration. There are cases where the operating conditions vary widely or are not well enough known to permit clearcut refractory selection, so it may be necessary to take an intuitive approach with a best-guess choice based on pertinent experience or an in-service comparison of several refractory products. There are examples of the same kind of furnace at two different sites, which would be expected to have identical refractory performance but instead are widely different because of differences in operation, feed material, additives, etc.

A specification is a description of the detailed requirements for a refractory order that should be included in the purchasing paperwork, to clearly establish the acceptance criteria. In the absence of purchase specifications, the consistency and quality of incoming refractory shipments will depend upon the QC/SPC program of the manufacturer. Refractory users should consider a broad range of factors for specification, to avoid excessive product variations and associated problems. There are numerous factors that can be specified; some examples include porosity and strength range, hot strength, reheat change, creep, brick dimensions and warpage, castable bag weights, workability limits for plastic refractories, ultrasonic velocity range for brick/shapes, shrink-wrapping of pallets, and chemistry variations. For specifications to be meaningful and realistic, they must be developed based on discussions with refractory suppliers. Once prepared, specifications should be regularly reviewed and updated to reflect realistic, current information.

The following examples illustrate deficiencies in refractory selection or specification:

○ Silicon carbide blocks were an improper choice for an incinerator operating at 1800 °F, with steam and alkali present in the environment. The block softened and cracked prematurely, requiring unexpected repair and replacement.
○ Purchase specifications designated porosity, bulk density, reheat change, and other property limits for a high alumina brick, but a significant number of the bricks received were outside the specified ranges. Even though test results showed suspect brick, they were installed in a glass furnace crown, which failed within weeks.
○ A heat-setting mortar was used for a brick lining in which the operating temperature was not high enough to initiate bond development. The lack of mortar bond contributed to collapse of the lining.
○ A 90 % alumina brick was specified for a furnace roof, but an 85 % alumina brick was substituted at a significant cost savings. The roof slumped prematurely and had to be replaced with 90 % alumina brick.
○ A dry vibration refractory can have low strength near the operating temperature of a furnace, especially if a mix with proper bond content is not selected. There have been cases in coreless induction furnaces where the choice of a dry vibration refractory with inadequate bond collapsed on the first movement of the furnace.

2.3 Refractory Quality and/or Properties

As noted above, refractories are variable materials. But given the statistical analysis and monitoring capabilities available today, it is possible for the variation of refractories, as produced, to be well controlled within acceptable limits. Despite the regular monitoring of refractory raw materials and production by the manufacturers, there are occasions when marginal or off-quality refractories are shipped to a customer. The deficiencies can be major or minor, and the extent of variation can range from a small to large percentage of any given lot.

The possibility of variations within and between refractory shipments, increases the importance of (1) purchase specifications, (2) review of the manufacturer's quality control data for each shipment, and (3) random confirmation testing (until proven unnecessary). In the absence of these precautions, there is the possibility that off-quality refractory could be installed in a furnace/reactor. Problems due to refractory quality are avoidable because they usually can be easily detected, sometimes with quick and simple check tests. For example, non-destructive sonic testing [1] can be used to verify the quality and consistency of refractory brick. Fig. 1 shows sonic test results [2] for several lots of the same brick product, in which one shipment was different. By detecting such a deviation, followed by confirmation of

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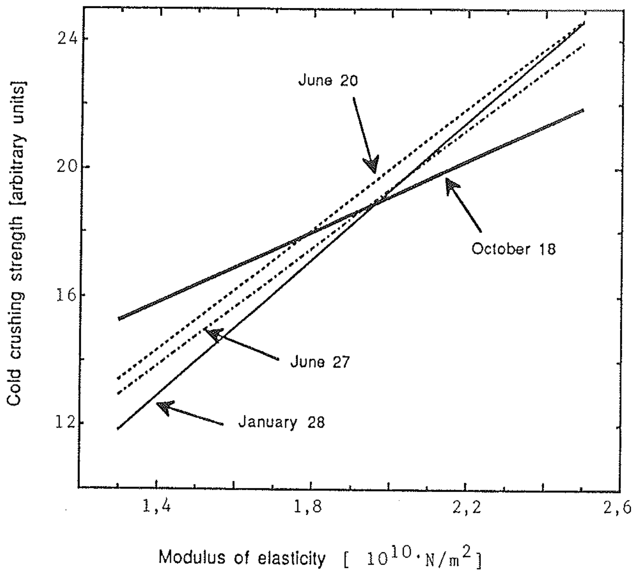

Fig. 1 Graph showing linear regression plots correlating cold crushing strength with non-destructive sonic results for four different shipments of the same refractory brick product [2]; it is seen that the October 18 shipment is different from the other three shipments.

the significance, a user has the opportunity to take appropriate action(s) and avoid possible problems and expenses.

Fig. 2 is included to more clearly illustrate the variability of refractory brick [2] as-produced. The data show different strength ranges for three shipments of the same brick product. Lot 1 shows good consistency with little strength variability. Lot 2 has a wide strength range and appears to contain brick from two production lots, including high-strength and low strength groups. Lot 3 has a wide strength range and is extremely variable.

Refractory properties can contribute to problems from several aspects. As mentioned above, property deficiencies that arise in the production process can result in refractories that will not perform as expected. Also there are cases where an inadequate refractory is chosen for an application (see 2.2 above), and even though the properties are excellent and within specification, the refractory can deteriorate or fail early because it is not appropriate for the application. Especially when refractory users do not know the full details of their process or change something in the operation, an inadequate or wrong refractory or lining design can be selected and installed.

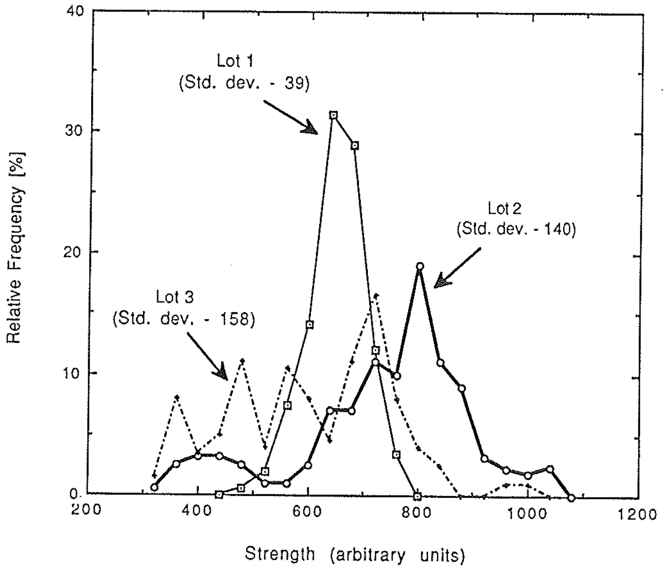

Fig. 2 Graph showing the strength range for three shipments of the same refractory brick product; lot 1 has a narrow range of strength variation, but Lots 2 and 3 have a much wider strength range [2]

Many factors in the shipment and storage of refractories can be detrimental to properties and performance, but these factors are sometimes not recognized or are overlooked. Perfectly good refractory can be shipped from the manufacturer's plant, but exposure to freezing conditions, moisture, induced vibration, forklift-caused impact, etc., during shipment or storage can degrade the properties. Some refractories, e.g. plastics and mortars, have a shelf life, and should not be used after the expiration date. So it is important to consider if any of these factors are applicable, before using a refractory.

A few examples of costly problems and failures, that occurred because marginal or off-quality refractories were not detected and were installed in a furnace/reactor, are given below:

- ○ Two lots of bonded alumina-zircon-silica (AZS) brick were received. One lot was marginal and the other was well below the typical properties. Use of the two lots of brick in a glass furnace shadow wall resulted in premature slumping and collapse within one year.
- ○ Quality control data from the manufacturer showed that up to 80% of the bottom block tested did not meet the porosity and strength guidelines. This fact was not detected by the user and the block were installed. The result was rapid wear of the blast furnace bottom, with associated unplanned expenses and reduced production.
- ○ Some cans of a pre-mixed mortar (wet) arrived at a job site from a distributor in dry condition. The dried mortar was used by adding water on-site, but the brick lining in which the mortar was used failed prematurely by joint penetration.
- ○ Premature failure of an alumina-chrome brick lining in a chemical incinerator was attributed to the presence of internal laminations. Sonic testing of the next shipment of the same alumina-chrome brick product revealed pallets on which 50...98 % of the brick had internal laminations.
- ○ A change or deviation in the particle sizing of an alumina castable by the manufacturer, resulted in a more permeable material after firing. Use of this castable in an induction furnace resulted in increased metal penetration, and much faster wear.

2.4 Installation of the Refractory Lining

The installation of a refractory lining plays a critical role in its performance, and thus can contribute to failure or short performance life. As with many of the other important factors, the contribution of installation to performance life is frequently not recognized or is overlooked. The installation steps for a refractory lining should be carefully specified, closely monitored, and inspected by qualified personnel to ensure that proper practices based on proven experience are always followed. It is advisable to maintain a daily log of installation facts and observations. By deviating from proper installation practices, a good refractory can be changed to an off-quality refractory with a significant change in the performance character.

Several examples of installation-related concerns are given below:

- ○ In many brick linings, a mortar joint thickness of 2...3 mm (1/8") or less is specified, but in practice it is common to find mortar joints up to 9...12 mm (3/8...1/2"), or greater. The mortar joint thickness must be carefully controlled during installation, to help avoid rapid reaction and penetration in service later.
- ○ The instructions for a castable refractory specify the addition of 6 mass-% water to give optimum properties. However, the workers feel the consistency is too stiff for easy placement, so they use a water addition of 9...10 mass-% to make a more fluid mix for easier placement, which will increase the porosity and reduce the strength of the fired castable and increase the potential for premature deterioration or failure.
- ○ Installers changed an insulating gunning refractory in the field, by adding granular fireclay to the mix. This unauthorized change by the installers resulted in increased heat flow through the lining, and increased expansion of the outer stainless steel shell, causing cracking of the refractory inside. The alteration of a refractory mixture in the field should be permitted only if proper approval is obtained.
- ○ Shifting of the mold in a U-bend reformer during installation of the castable lining resulted in a deformity that led to the development of major cracks through the lining. Penetration of heat and steam through the cracks caused the outer steel to be progressively deformed. A crack developed in the steel, and a steam explosion followed.
- ○ A non-ferrous metal reactor was lined with castable refractory. Water for mixing the castable was obtained from muddy canals nearby. The solids (mud) in the water altered the castable and caused rapid failure of the lining.
- ○ During the placement of a rammed refractory lining, frequently the proper precautions are not taken to use consistent ramming pressure and to fully bond the sequential layers of material as they are installed. This can result in regions of high porosity and open laminations (cracks) which can cause early failure of the lining.

2.5 Curing, Startup, and Maintenance of a Refractory Lining

The curing, startup, and maintenance refractories is important for achieving optimum lining performance. Curing refers to the treatment period after installation but prior to commercial operation, and startup begins with the initiation of heating to commence production. Maintenance is the repair of normal or unusual refractory wear or damage that occurs during lining service. Such repairs may be done with the furnace/reactor in a hot condition or at room temperature after cool-down of the system. There are various guidelines and accepted practices that need to be followed to avoid problems with these activities.

For example, with castable refractories (traditional, low-cement, no cement, etc.), the water used for mixing should be clean (drinkable), and the mixing, placement, and curing conditions should be closely controlled, all in accordance with the recommendations of the manufacturer. The recommended heat-up schedule for various refractories will include holding periods at several temperatures to allow moisture escape. The common desire is to get the furnace/reactor on-line and to produce as soon as possible, so the suggested curing and startup procedures may be shortened or overlooked by the operator. But if the recommendations of the refractory manufacturer are not followed, the properties of the refractory can be altered, and, in the worst cases, there can be explosions, cracking, or other problems.

Arrangements can be made to have refractory suppliers and/or contractors supervise or conduct on-site installation, curing, and startup. There have been various innovations in recent years which permit faster heatup of monolithic refractories, but there are still guidelines to be followed. The rate of cool-down of a refractory lining is also very important, as major damage can be induced. There are cases where water is sprayed into a hot furnace, to speed cool-down, with no knowledge that the refractory is being damaged and the life shortened.

Several examples of problems associated with startup, curing, and maintenance are given below:

- ○ There have been instances where monolithic refractory mixes containing aluminum powder reacted with water during curing, forming hydrogen gas. There have been tragic explosions due to this reaction.
- ○ Upon initial startup of a chemical reactor there was cracking, crushing, and spalling of brick in a ring structure. The problem occurred on start-up, and may have been aggravated by fast heat-up, but a contributing factor was insufficient allowance for thermal expansion in the installation.
- ○ The top 9" (22 cm) of the refractory lining in a coreless induction furnace deteriorated quicker than the rest of the lining. The top 9" section of refractory was removed and replaced by a different type of refractory, creating an interface (joint) below the metal line. When the repaired furnace was returned to service, metal penetrated the interface and ran out.
- ○ Localized wear areas (holes) developed in the refractory lining of a reheat furnace. The areas were patched with alumina plastic refractory without cleaning the surface or exposing the underlying unaltered refractory. On startup of the furnace, most of the patches fell off.

2.6 Operation of the System

The operation of a furnace/reactor has a significant and direct effect on the performance of a refractory lining. Included are factors such as operating temperature, pressure, production schedules, furnace movement, and other physical factors. It is common that production is the main concern in a plant, with little or no regard to the effect(s) of operations on the refractory lining and its performance. This fact is understandable because an acceptable production/profit level must be maintained for a plant to be commercially viable.

But if a furnace/reactor is pushed harder or longer, in order to meet production requirements, there can be premature wear and even catastrophic failure of localized or large sections of the refractory lining. As shown in Fig. 3 [3], for the operating temperature range of a furnace/reactor, intermittent or prolonged operation at "high" temperature will cause a rapid and progressive increase in the rate of refractory wear. If operators do not realize this fact, refractory life can suffer. In addition to the temperature level, the rate of temperature change on heating and cooling can lead to cracking and spalling (material loss), and, even though a furnace/reactor usually operates in a reasonable temperature range, refractory damage can be induced by upsets or excursions.

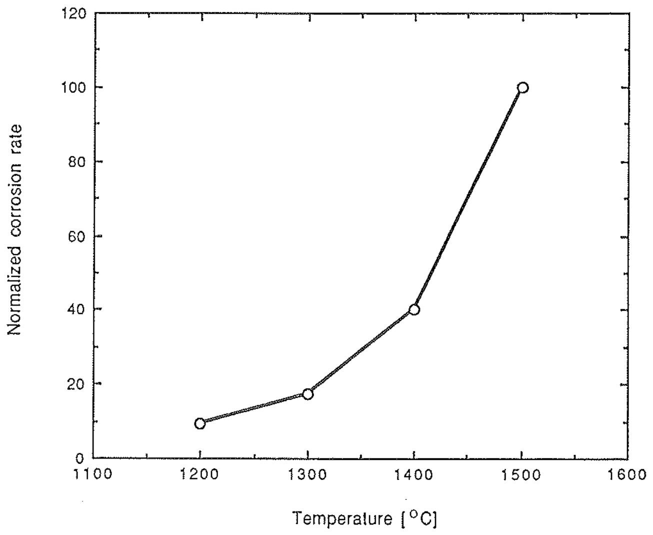

Fig. 3 Graph showing the relative corrosion rate for a representative glass tank refractory tested at various temperatures; these data illustrate the general fact that the corrosion and chemical attack of refractories progressively increase with increasing temperature [3]

In addition to the possible effects of temperature and/or pressure on refractories, it should be recognized that there are many other operating factors that can contribute to problems; a few examples are given below:

- ○ Dumping hot metal (molten) or scrap into a furnace can cause refractory damage by impact and erosion. In some cases the refractory lining is made thicker in those regions where charge materials are dumped.
- ○ Charging a chemical slurry into a reactor through an eroded stainless steel roof chute allowed reactive material to run down the refractory walls and erode the mortar and brick, instead of dropping onto the reactor floor where refractories with better chemical resistance were installed. Also, this reactor did not have a control thermocouple, so it was operated by "feel" because the actual temperature was not known.
- ○ Injection (location, rate, and duration) of oxygen into a furnace/reactor can be very damaging; e.g., an inexperienced basic oxygen furnace operator positioned the oxygen lance too near the refractory wall and burned a hole through the lining and steel shell, causing a runout of molten steel

- High-production periods when a furnace is tilted/poured more often than usual, can cause increased abrasion and chemical attack, leading to faster wear of the refractory lining
- Spraying water onto the refractory wall in the quench section of a chemical reactor can enhance refractory damage by cracking and spalling
- In a campaign where there are heats or production periods when a furnace/reactor is held at temperatures above the typical operating limit, a shorter refractory life can be expected than for a campaign in which operation remains within controlled limits.

Each system should be carefully reviewed to define the important operating variables and to establish the optimum operating procedures and acceptable ranges. There are various examples of the same kind of furnace at two different sites that have widely different refractory performance lives because of unrecognized major or minor differences in operation. So it is not wise to assume that the refractory requirements will be the same for two furnaces/reactors, even though they appear to be the same.

2.7 Chemical Characteristics of the System/Process

Refractories are reacted and altered in service according to the principles of thermochemistry (phase equilibrium). Factors like thermal gradient, temperature, chemical concentration, pressure, particle surface area, structure, and others affect the rate and degree of refractory change in service. Because refractories commonly have open porosity (e.g. 15...20 %), including microcracks, there are usually openings for reactants to enter the refractory structure. The reaction effects associated with the openings in refractories can range from minimal to extensive depending on the material, the structure, the conditions and other factors.

The absence of pores in a refractory does not eliminate the possibility of reaction in service. Fused cast refractories, which can have 0 % porosity, are progressively eroded in a glass furnace due to chemical solution at temperature. Simulated high-temperature exposure tests (slag, metal, glass, etc.) are available to indicate the relative or quantitative extent of refractory reaction in a given environment. While pores can be detrimental to refractory life from the standpoint of chemical attack, they can be beneficial by giving improved thermal shock resistance. The relationship between refractory structure and reactivity is complex and not always easy to interpret, especially if meaningful data and experience are not available. In many cases, there are published phase diagrams that can be used to predict the reaction effects that will occur in service, but more phase diagrams are needed, because frequently the key phase diagram(s) needed to interpret a refractory deterioration question is not available. Work is underway by the *American Ceramic Society* and the *National Institute for Standards and Testing (NIST)* to improve the situation by increased review and computerization efforts.

Because refractories react in service, it is important to know the chemical characteristics of the system. Obviously the major chemical species have an important effect, but also the minor species present can cause accelerated refractory deterioration. A full documentation (start to finish) of the chemistry of a system is essential for proper lining design development, including selection of the most appropriate refractories. These data also provide background information necessary for a review of the operation of a furnace/reactor to minimize or eliminate the detrimental chemical effects. A detailed system evaluation can result in a variety of benefits, including improved refractory performance.

A few examples of detrimental chemical effects are given below:

- Dumping of a flux material (e.g. B_2O_3) directly onto the refractory lining in a non-ferrous metal melting furnace caused rapid chemical attack
- Slagging practices can cause rapid wear of a refractory lining, especially the mortar joints
- The presence of fluorides (e.g. CaF_2, NaF, HF) in a system can result in rapid erosion and deterioration of refractories
- Addition of extra calcium aluminum cement to a refractory castable resulted in the reduction of the use temperature and slumping of a wall section upon start-up of a furnace
- Burning of wood chips in a boiler system resulted in an alkali-rich ash residue that caused extensive melting of the refractory lining
- Injection of liquid sodium hydroxide into an incinerator directly onto the refractory wall caused chemical attack, spalling, and rapid failure of the fireclay lining.

3 Other Concerns

The seven main factors that contribute to refractory problems (discussed above) can usually be readily confirmed and documented by discussion, inspection, and analysis. But there are other contributing factors that may be less apparent and more difficult to confirm. Some examples of these other concerns are:

- The role of management in promoting refractories awareness and education will govern the in-plant attention to refractories and directly affect the potential for success or failure. The role of management can be learned by direct communications and/or indirectly by observing plant cleanliness/upkeep, safety practices, maintenance policies, labor attitudes, worker education, etc.
- People, in-house biases, politics, personalities, etc. can delay the evaluation and solution of an ongoing refractory problem. In such cases, experienced insight may be needed to fully assess the situation and stimulate needed action. Frequently, "fresh eyes" can quickly detect the cause(s) of refractory problems and overcome ongoing difficulties.
- Time/schedule constraints can have a negative impact on the installation of a refractory lining because of the need to act quickly, which can increase the chance of errors and oversights. Sometimes, off-quality refractories must be used for a lining because it is not feasible to wait for a replacement shipment. Similarly it may be necessary to use a less experienced installation crew rather than waiting for an experienced crew.
- Cost-cutting measures by a low-bid contractor due to financial troubles, the desire to increase profit, or other economic factors can result in deviations from the materials specified, reduction in the material used (e.g. mortar), use of inexperienced workers, change in the installation technique, or other shortcomings
- Budget limits and contractual matters, such as a warranty clause, penalty payments, storage surcharge, union requirements, etc., can result in practical decisions that contribute to a refractory lining which is less than optimum
- Weather or environmental conditions serve to accentuate several of the main factors and should always receive attention. Temperatures can be too hot or too cold to achieve an optimum lining: for example, the refractory properties can be affected, or a cold steel shell during installation can result in a loose lining that will crack when heated. Working conditions can be too cold/hot, too dusty/dirty, too cramped, unsafe, or have noxious odors, so that the workers are not able to produce a good lining.
- Purchasing of refractories solely on the basis of price, without regard to quality, service, property confirmation, etc. can result in ongoing problems because the refractories chosen may be improper or otherwise inadequate.

4 Summary

Refractories are essential materials that are used throughout industry worldwide for the profitable production of many important commodities. The conditions that refractories endure and their performance life are different in the many different industrial applications. The performance of refractories is affected by many factors, as well as many people.

Seven main reasons for refractory problems are identified, based on facts that can be readily determined and documented by discussion, inspection and analysis. It is common that refractory problems in industry result from some combination of these seven factors. But it should be recognized that there are other factors that are not as apparent and documentable, which can also contribute to refractory problems. Some of these other factors are the role of management, people, weather, time constraints, etc.

In some plants, refractories receive little or no attention because they are a small and an insignificant cost factor in the overall operation, if things go right. But when a problem occurs, the cost effect of refractories can then be greatly magnified with downtime, lost production, repair costs, capital expenses, legal fees, etc. Attention to refractories can be considered as insurance against unnecessary and unexpected major expenses.

The evaluation of a refractory problem in an industrial furnace or reactor should start broad, considering the "big picture", and then focus on the specific factors indicated. Sometimes analyses initially focus on only one or several factors that someone has predetermined to be the main culprits, whereby important contributing factors are completely missed. A proper evaluation is best accomplished by complete cooperation and good communications between the refractory manufacturer, user, contractor, and all other parties involved. The thorough unbiased evaluation of a system, should result in improved understanding of the factors that control the refractory performance and life. The results and recommendations commonly provide a sound basis for a course of action that will reduce or eliminate refractory problems and avoid unnecessary expenses.

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Kurzfassung – Résumé – Resumen

Feuerfest-Probleme in der Industrie

Feuerfestmaterialien sind "das Rückgrat der Industrie" Trotz ihrer großen Bedeutung werden sie laufend mißverstanden, nebensächlich behandelt und/oder mißbraucht. Die Resultate können zu extremer Zerstörung führen, sie können kostspielig sein und sogar tragische Züge annehmen. Im Beitrag werden sieben Hauptgründe untersucht, die zu Feuerfest-Probleme in der Industrie führen können. Weitere sieben Faktoren, die beteiligt sind, werden beschrieben. Zahlreiche Beispiele aus der Praxis werden gegeben. Basierend auf einem verbesserten Verständnis für die Ursachen der Feuerfest-Probleme – begleitet von einer ernsthaften Betrachtung aller beteiligten Faktoren – sollte es möglich werden, all unnötigen oder unvorhergesehenen Ausgaben zu reduzieren oder ganz zu eliminieren.

Revue des problèmes de réfractaires dans l'industrie

Les réfractaires constituent "l'épine dorsale" de l'industrie. Mais en dépit de leur importance, les réfractaires sont souvent mal connus, surestimés et/ou ignorés. Les résultats peuvent être néfastes, coûteux, voire même tragiques. Cet article définit sept raisons principales d'examen des problèmes de réfractaires dans l'industrie, et note sept autres facteurs pertinents. On donne de nombreux exemples pratiques. En s'appuyant sur une compréhension améliorée des problèmes de réfractaires et sur une étude approfondie des facteurs en jeu, on peut réduire ou éliminer les principales dépenses inutiles et inattendues.

Resumen de los problemas refractarios en la industria

Los refractarios son la "columna vertebral de la industria". A pesar de su importancia, los refractarios a menudo se aplican mal, no son tenidos en cuenta o se abusa de ellos. Los resultados pueden conducir a un deterioro extremo y pueden ser muy costosos. Este artículo define siete causas principales de problemas con refractarios en la industria, y presenta otros siete factores que contribuyen a ello. Se presentan numerosos ejemplos prácticos. Luego de comprender mejor las causas de los problemas con los refractarios, y de un resumen de los factores de influencia, es posible reducir o eliminar importantes costos innecesarios e inesperados. □