

Refractories Applications *and News*

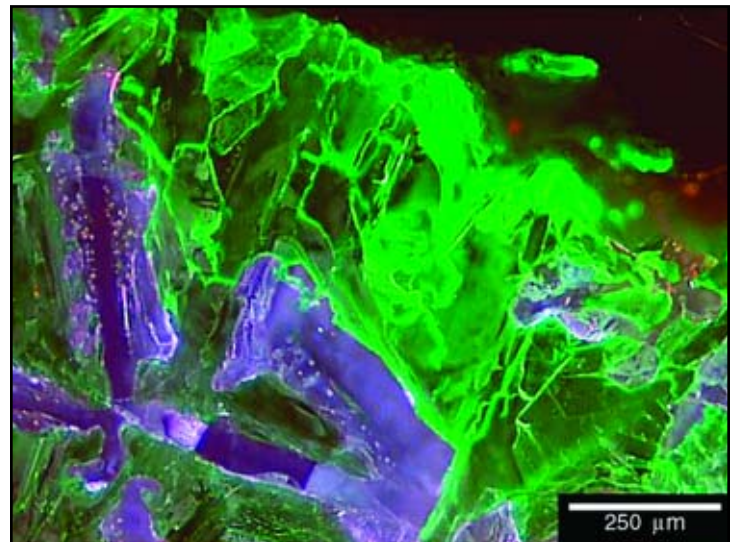
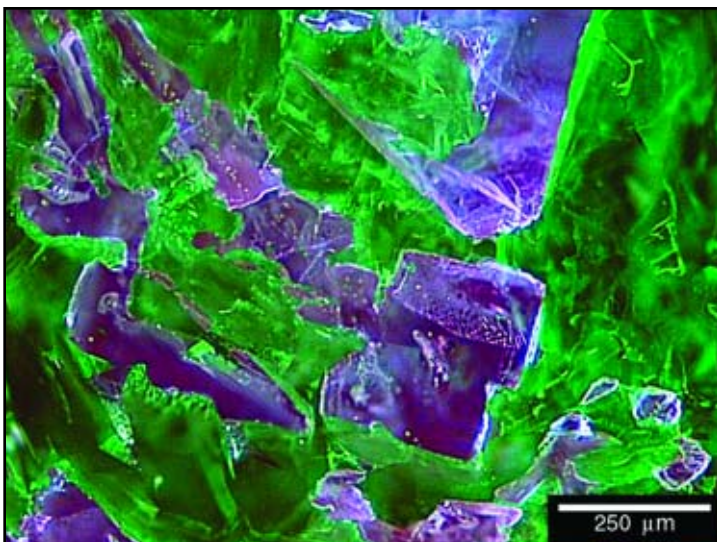


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Technology Bimonthly for the Global Refractories Industries

Special Issue on Refractories for Gasifiers



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The top front cover image is from an article by Wade A. Taber, Application Engineer, Saint-Gobain Ceramics/Energy Systems, "Refractories for Gasification" Volume 8, Number 4, July August 2003. This article reviewed the process, examined refractory challenges and described the common failure mechanisms of refractories in coal gasification. The image is a rendered gasifier assembly. The inner (purple) layer depicts the hot face and the safety layer is white. The yellow shapes and monolithics represent low duty materials used primarily for insulation. The generalized steel shell is shown in gray, with expansion joint details removed.

The following is a quotation from Wade Tabor illustrating the importance of proper refractory selection and design, "The refractory lining is an integral part in the majority of entrained flow gasifiers. Proper material selection and well-executed lining designs are necessary to insure the longest possible service life, as even a minor lining failure could cause a shutdown of the gasifier and dependent processes".

The bottom two micrographs are cathodoluminescence images of unaltered (left) and altered (right) fused cast alumina with a chemistry of 95% Al₂O₃, 4% Na₂O, 0.5% SiO₂, density of 3.34g/cc and 16% porosity. The altered material was exposed for 240 hours to commercial black liquor smelt under argon atmosphere at 1000°C by a cup test. Alpha-alumina exhibits a blue or blue-violet cathodoluminescent characteristic color and beta-alumina exhibits a green characteristic color. The material in the upper right hand corner in contact with smelt (black) of the altered material micrograph exhibits a brighter green cathodoluminescent characteristic color. The change in characteristic color is due to infiltration of smelt causing an increase in the amount of soda in the beta-alumina. Small particles of beta-alumina are flaking off the surface due to the associated volume expansion of the beta-alumina. The alumina will continue to incorporate additional soda leading to continued volume expansion until soda aluminate formation is complete. The associated volume expansion will cause chemical spalling of the fused cast alumina in contact with the smelt. These micrographs are from an unpublished report by William L. Headrick and Musa Karakus at University of Missouri-Rolla to James Keiser at Oak Ridge National Laboratories. 

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Instructions for the preparation of articles to be submitted for possible publication in this magazine are available from the Assistant Editor, Mary Lee, leem@umr.edu, (573)341-6561, University of Missouri-Rolla, 223 McNutt Hall, Rolla, MO 65409.

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2004 REFRACTORIES RELATED MEETINGS

September 9-12, **5th International Trade Fair & Seminar 2004 on Minerals, Metals, Metallurgy & Minerals**; held at Pragati Maidan, New Delhi; sponsored by the Indian Institute of Metals; www.tafcon.com

September 19-22, **The 8th International Congress of Applied Mineralogy (ICAM 2004)**, organized by the International Council for Applied Mineralogy (ICAM) - Commission on Applied Mineralogy of the International Mineralogical Association (IMA-CAM), Aguas de Lindoia, São Paulo, Brazil, www.appliedmineralogy.org/icam

September 19-23, **10th International Symposium on Superalloys**, Champion, PA, sponsored by the Minerals, Metals & Materials Society (TMS); Tel: 724/776-9000; E-mail: tmsgeneral@tms.org; www.tms.org

September 20-23, **3rd International Nickel, Stainless Steel & Alloys & Special Steels Forum**; The Hilton, Prague, Czech Republic; Tel: 00442078279977; http://www.metalbulletin.com/welcome_2003.asp

September 22-24, **Aluminum 2004 – 5th World Trade Fair & Conference**, Messe Essen, Germany; Tel: +49-211-90191-202; E-mail: info@Aluminum-messe.com; www.Aluminum2004.com

September 23-24, **FURNACES North America 2004**, Nashville, Tennessee, Tel: 904/249-0459; www.fna2004.com

September 27-30, **MineExpo 2004 International**, Las Vegas, NV, Sponsored by the National Mining Association, www.minexpo.com/

October 5-7, **Short Course on Advanced Techniques for Pore Structure Characterization**; Ithaca, NY; Tel: 607/257-5544 ext. 13; E-mail: conference@pmiapp.com; www.pmiapp.com

October 3-6, **Fractography of Advanced Ceramics**, Poprad, Slovak Republic, www.immov.saske.sk/CONFER/fac2004.htm

October 4-6, **32nd Annual Conference on Thermal Analysis and Applications**, North American Thermal Analysis Society (NATAS), Williamsburg, VA; Tel: (916) 922-7032; Fax: (916) 922-7379, E-mail: natas.info@mindspring.com; www.natasinfo.org

October 13-14, **47th International Colloquium on Refractories 2004**, Refractories for Metallurgy EUROGRESS, Aachen, Germany, Forschungsgemeinschaft Feuerfest e.V. - Feuerfest-Kolloquium -An der Elisabethkirche 27, D-53113 Bonn, Tel:++49-228-91508-45, Fax:++49-228-91508-55, E-mail: 2004@feuerfest-kolloquium.de, www.feuerfest-kolloquium.de

October 13-15, **4th International Tube and Pipe Industry Technology Exhibition for Korea**, Busan Exhibition and Convention Center, Seoul, Korea, www.e-pipe.co.kr/exhibition2004/img/eng1.gif or e-mail:exhibition@e-pipe.co.kr

October 18-19, **Short Course on Refractory Applications for FCC Units, Process Heaters and Boilers**, Hotel Sofitel Houston, Houston, Texas, E-mail: seminars@petroleumrefining.com; www.petroleumrefining.com

October 22-24, **China Liaoning International Magnesia Materials Exposition and Technological Exchange Conference**, Science Centrum Conference and Exhibition Center, Shenyang, China, Tel: 0086-24-23831926 or 0086-13002423646, Fax: 0086-24-23286070, E-mail: Christopher8031@yahoo.com.cn, www.lnmo.com.cn

October 31-November 3, **3rd International Symposium on the Science of Engineering Ceramics**, Osaka, Japan, Tel: 81-52-739-0155, E-mail: t-ohji@aist.go.jp

November 3-5, **15th IAS Rolling Conference, 2nd IAS Conference on Uses of Steel**, Instituto Argentino de Siderurgia, Hotel Colonial, San Nicolas, Argentina, Contact: Cristian Genzano, IAS, E-mail: genzano@siderurgia.org.ar, Tel: 54-3461 460803, Fax: 54-3461 462989, www.siderurgia.org.ar/seminario/call_for_papers.htm.

November 7-10, **32nd ALAFAR, Congress of the Latin American Association of Refractories Manufacturers**, Antigua, Guatemala, mpereyo@thermalceramics.co

November 9-12, **30th International Cokemaking Conference**, Malenovice, Czech Republic, Organizer Czech Cokemaking Society, Contact:Mr.Kristof, Tel/Fax +420 596 922561, E-mail:j.kristof@quick.cz

December 6-8, **International Symposium on Advanced Materials and Processing**, Kharagpur, India, www.iitkgp.ernet.in/departments/home.php?deptcode=MS

NINE YEARS OF *REFRACTORIES APPLICATIONS* & *NEWS*

Mariano Velez, Editor



Mariano Velez

The first issue of *Refractories Applications* appeared in September 1996, as an “irregular” tabloid dedicated to the refractories industry. By irregular I mean that the issues were appearing two or three times a year previous to 2000. In 2002 the name was changed to *Refractories Applications & News* to include TRI (The Refractories Institute) news section in each issue, changing the format to a magazine style, and committing efforts to publish it six times per year. The objectives of *RA&N* were

and have been to “transmit current information ranging from technical tips to full blown treatments of technology, which will enable users, and installers of refractories to make optimal use of them” as is presented in the current **Author Guidelines** (www.ranews.info).

With the next issues of *RA&N*, the Editorial Board is planning to include a “Transactions Section” (*RA Transactions*) to publish refereed articles dealing with refractories and high-temperature materials. This section will include complete technical articles regarding basic and applied research; perhaps one article of this category per issue, possibly more if interest is high. We are aiming to have this “Transactions Section” of *RA&N* as one of the most qualified platforms for peer-reviewed technical articles dealing with refractories. To accomplish this objective we are planning a three-four week turnaround, electronic review by world-wide experts in the field of refractories. Articles should be written within the guidelines of the *J. Am. Ceram. Soc.* with a seven page limit including figures and tables. In keeping with the major international conferences and journals, English will be the required language. This is an important rule for non-native English speakers that must be enforced. Information and assistance related to this topic can be obtained from our Corresponding Editor, Laurel Sheppard, at: lashpubs@infinet.com. The ultimate goal is to reestablish a venue for the international exchange of technical data. Dr. Jeff Smith, Associate Professor of Ceramic Engineering at UMR, has agreed to be the editor of *RA Transactions* and we are currently in the process of assembling the team of reviewers to referee the submitted articles. For additional information on submitting articles contact Mary Lee at: leem@umr.edu. This is an exciting time for the Editorial Board as this type of refereed section of *RA&N* had been a goal of Professor Moore’s since the inception of the magazine.

This current issue was organized by Dr. Bill Headrick to include articles relevant to refractories for gasification. It showcases a company profile (Future Energy, Germany), and a Research Institution Profile (US DOE Albany Research Center). The feature article is also from the US DOE Albany Research Center and summarizes refractory materials used in slagging gasifiers. The importance of this topic is emphasized by the US Department of Energy funding research in refractories areas such as:

- Ceramic and refractory components for aluminum melting and casting;

- Materials for high-temperature black liquor gasification; and
- Multifunctional metallic and refractory materials for handling of molten metals

More details on advanced materials topics can be found in the US DOE Energy Efficiency and Renewable Energy website: www.eere.energy.gov. UMR is partnering ORNL in the program on materials for high-temperature black liquor gasification. Another UMR current DOE program is the fabrication of high-resistant Fe-phosphate glass fibers that can be used either as concrete reinforcement or asbestos replacement. These fibers can perhaps be used also as reinforcement of refractory concretes and I would like to hear comments regarding such potential application.

I want to remind everyone of two major refractory events coming. First of all, the ALAFAR (www.alafar.org) meeting in Antigua, Guatemala on November 7-10. Second, the abstract deadline for UNITECR’05 (www.unitecr.org), due on November 30th. **RA&N**

DR. ROBERT E. MOORE, THE FIRST RECIPIENT OF THE WILLIAM T. TREDENNICK AWARD



Ellen Moore accepts the William T. Tredennick award from TRI Chairman, John Turner.

Mrs. Ellen Moore accepted the William T. Tredennick award from TRI Chairman John Turner in honor of the memory of her late husband, Dr. Robert E. Moore. The Refractories Institute recently established the award to recognize individuals who have made a significant and lasting contribution to the refractories community during their careers. The award is named for William Tredennick, a founder of Resco Products and the longest serving TRI Board member until his death in 1996. The TRI Board of Directors unanimously chose Bob Moore to be the first recipient of the award in honor of his lifetime contribution to the industry.

TRI SPRING MEMBERSHIP MEETING

The 54th Annual Spring membership Meeting of The Refractories Institute was held at The Homestead in Hot Springs, Virginia, June 9-11, 2004.

The guest speakers provided the backbone of the program. H. Avery Hilton, Jr., Executive Vice President of the CMC Steel Group, discussed the current situation in the steel industry. Consolidation continues, as does capacity rationalization. Many mills outsource abroad and companies like CMC and U. S. Steel are investing in foreign production facilities. While imports have slowed some due to tariffs and particularly the strong dollar, they continue to be a significant factor in the U.S. market. China has become a major steel producer, increasing pressure on raw material costs and concurrently contributing to a rise in steel prices. This is a double-edged sword. If China goes into recession, the entire world steel sector will feel its pain.

During the final part of his presentation, Mr. Hilton discussed the question, "How can refractory companies help the steel industry improve its bottom line and how can refractory producers be more of a partner with them?" CMC has conducted a survey of its manufacturing personnel on the subject. These are some of the answers received: supply monolithic ladle working linings; help decrease downtime; use robotics for refractory installation; offer "turnkey" service; develop reheat furnace refractories that are more durable to expansion and corrosion and have longer shelf life; recycling; understand balance between cost and life; offer more technical expertise and training; offer consignment inventories; develop software programs and training for slag analysis; develop means for in-service measurement of refractory thickness, either with lasers or optics; offer flat cost per ton for complete refractory service. Finally, better refractory life and lower conversion cost can only be achieved by superior quality refractories and consistent operating practices.

Stephen Larkin, President of The Aluminum Association, discussed the state of the world and U.S. aluminum markets.

Total 2003 aluminum consumption in the US and Canada was estimated at 23.28 billion pounds, off 1.4 percent from 2002.

Aluminum consumption in its largest market—transportation—increased some 3.3 percent in 2003 over 2002. However, a leveling off of auto and light truck build rates to 6.2 billion pounds, up just 1.3 percent. The bright spot was the production of trailers and semi-trailers—up some 19.5 percent to 588 million pounds. This increase was largely driven by new EPA mileage regulations.

Aluminum consumption in its second largest market, container and packaging, was little changed in 2003 compared with 2002. Aluminum can stock use fell by 51 million pounds in 2003, or 1.3 percent. Conversely, aluminum foil for packaging was up by 15 million pounds, or 1.9 percent. The overall decline was 0.8 percent in 2003 over 2002.

Shipments of aluminum ingot for castings, exports and destructive uses increased 10.7 percent for last year totaling 2.04 billion pounds. Led by a strong demand for flat rolled products (up 10.2 percent) and extrusions (up 8.2 percent), shipments of aluminum mill products totaled an estimated 3.87 billion pounds, an increase of 9.3 percent.

According to Larkin, over 40 percent of the US aluminum supply is imported—in the form of primary and secondary ingot or aluminum semi-fabricated products such as sheet and extrusions. Over 60 percent of imports

come from facilities in Canada with another 15 percent of imports coming from Russia.

Global primary production totaled an estimated 27.7 million metric tons in 2003. At just under 10 percent (9.8) of the total, the U.S. ranks 4th behind China at 19.7 percent, Russia at 12.5 percent, and Canada (10.1 percent)

Mr. Larkin also discussed outreach programs being conducted by the Aluminum Association on behalf of its members. One such effort that refractory producers who sell to the aluminum industry should be aware of is "Aluminum 2005". This event will be held in Chicago in conjunction with National Manufacturing Week at McCormick Place, March 7-10, 2005. Joining the Aluminum Association in that effort are the Aluminum Extruders Council, the North American Die Casters Association, the Non Ferrous Founders Association, and the Metal Service Center Institute.

Victor E. Schwartz, Washington-based attorney with the firm of Shook Hardy & Bacon, then briefed the group in the status of civil justice in the U.S. Schwartz is an acknowledged leader in the fight for tort reform in the United States.

Mr. Schwartz discussed how plaintiffs' lawyers operate. They will vilify your company in the press, bring the government down on you, and even go to the investor community. They like to regulate through litigation and seek help when they can from state attorneys general.

Schwartz discussed some legislative initiatives at the state level to help curb abuses. Some legislatures have or will consider the Private Attorney Retention Act which would rein in state attorneys general, the Appeal Bond Waiver Act which preserves the right to appeal outrageous decisions, and the Jury Patriotism Act which would prevent against runaway juries. The Jury Patriotism Act has recently been enacted in Mississippi, Missouri, Vermont, and Oklahoma.

For more information on these issues, visit the web sites of the American Tort Reform Association at www.atra.org and the American Legislative Exchange Council at www.alec.org.

TRI BOARD ELECTS OFFICERS

The TRI Board of Directors has elected John C. Morris, Jr., Riverside Refractories, as Chairman of the Institute, William K. Brown of Resco Products to be Vice Chairman, and Daniel W. Lease, Whetstone Technology, the new Treasurer of TRI, for a two year term ending in 2006. In addition to these three gentlemen, the TRI Executive Committee includes: Matt Colbert, Thermal Ceramics; David Gregory, LWB Refractories; William Kelly, Unifrax Corporation; and, John Turner, Allied Mineral Products.

Institute Welcomes New Member, Former Member Back

The TRI Board of Directors has approved the application of Munson Machinery Co., Inc. for Associate membership in the Institute. The official representative from Munson will be Ron Colicci. Also, TRI welcomes back Hotwork-USA as a Contractor/Installer member. Mike Hartley returns as the official representative.

RESCO HAS NEW SAFETY MANAGER

Greg McDonough has joined Resco Products as Safety Manager. He will be replacing Elaine Yarabinetz who will be leaving to spend more time with her new daughter. Elaine's good work with the TRI MACT Working

Continued on Page 25

UPDATE

ONE COMPONENT INSULATING PUMPABLES PROVIDE QUICK AND EASY REFRACTORY LINING REPAIR

With today's energy costs at such high levels, companies cannot afford to have gaps or voids in their furnace refractory lining that allow valuable heat to escape. Typical mineral fiber or other low duty materials used as backup insulation generally degrade over time, allowing heat to channel through. Thermal Ceramics has several products on the market that do an outstanding job of sealing these damaged areas in the existing lining construction, both on the cold face and hot face surfaces.

There are four pumpable product options available with selection dependent on temperature, strength and cost factors of the job:

- Kaowool Pumpable XTP - a 2000°F temperature capable, high quality-pumpable that is very strong and thermally stable up to its use limit.
- Kaowool Pumpable TP - a 2000°F rated, standard duty pumpable product with excellent insulating characteristics.
- Kaowool Pumpable HT - a 2400°F rated, low shrinkage product, suitable for applications at elevated temperatures.
- Therm-O-Hot Patch - an economical 1800°F vermiculite based product that can be pumped or sprayed

The Kaowool pumpable insulation products are supplied ready-to-use, with quick and easy delivery of the material through a variety of installation options - Kaowool Diaphragm pump (for medium - large jobs), air-powered Kaowool caulking gun (small jobs) or conventional hand caulk gun (very small jobs). The Kaowool Diaphragm Pump is available for either sale or rental while the Kaowool caulking gun can be purchased to handle 40oz. and 11 3/4oz. tubes.

The insulating pumpable products from Thermal Ceramics have been used around the world due to their ease of placement and demonstrated payback in reducing energy

loss. Reduction in furnace cold face temperatures are generally 100°F or more depending on the severity of the existing lining damage. Placement of the product on the cold side of the furnace can be completed while the unit is hot or cold, helping to minimize production downtime. Common pumpable applications include - re-insulating hot spots in utility boilers, industrial furnaces, and kilns, sealing around burner blocks and flues, and placement between fiber modules that have shrunk excessively.

Wendy Evans, Marketing Communications, Thermal Ceramics Americas, +1 706 796 4313, wmmorris@thermalceramics.com.

CHINA CERAMIC DIRECTORY 2003/2004 (ENGLISH EDITION) JUST PUBLISHED

Business Data International Inc., business and professional information provider, has recently announced that the English edition of "CHINA CERAMIC DIRECTORY 2003/2004" has been published. The directory lists more than 1280 leading ceramic and pottery enterprises, research institutes, associations, importers and exporters in China. It covers commonly used ceramics, porcelain products, sanitaryware, building ceramics, tile, electroceramics, refractories, technical and industrial ceramics, ceramic raw materials, equipment and machines, as well as publications. The directory provides information on each organization's name, address, telephone and fax numbers, e-mail addresses and websites, name of the director, registered capital, number of employees, history, production capacity and main products.

The 308-page directory (ISBN:0-9733166-0-8) is available from: Business Data International Inc., P. O. Box 28547, 5100 Verdun Avenue, Montreal, QC H4G 3L7, Canada, Fax:(514) 221-3281, info@businessdataint.com, or at: www.businessdataint.com

ALCOA TEAMS WITH THE DOE TO REDUCE ENERGY CONSUMPTION

The BestPractices Corporate Energy Management Case Study, Alcoa teams with the DOE to Reduce Energy Consumption may be obtained from the website in a pdf file format available on the BestPractices

Case Studies Page. Alcoa began working with the U.S. Department of Energy (DOE) in 1999 to identify opportunities for reducing energy consumption at its aluminum processing facilities. By performing plant-wide energy assessments, conducting employee training, and using DOE software tools and technical resources, Alcoa has successfully identified more than \$60 million in savings opportunities, and has reduced its operating costs by more than \$15 million. The six page summary can be viewed on the website below.

The BestPractices Case Studies Page also contains another Aluminum Case Study Corporate Energy Conservation Program for Alcoa North America Extrusions. More information: www.eere.energy.gov/industry/cfm/fullArticle.cfm?id=829.

INSULATING FIREBRICK, INC. ANNOUNCES WAREHOUSE EXPANSION

IFB, Inc. announced that their warehouse operation would expand in September to an 18,000 sq. ft. facility in Claysburg, Pa. This facility will stock over 200,000 pieces of ISO Certified Insulating Firebricks for immediate delivery to customers. The Insulating firebrick ranges from 2300 degree to 3000 degree in standard and special sizes. IFB, Inc. offers in-house machining capabilities for arches, keys, wedges, or custom shapes; and has emergency service 24/7. The main office will remain at: IFB, Inc., 610 East Butler Road, Butler, PA 16002, Tel: 724-282-1012/Fax: 724-285-7673, E-mail: Sales@Insulatingfirebrick.com, Web: www.Insulatingfirebrick.com

5th INTERNATIONAL CONFERENCE ON HIGH-TEMPERATURE CERAMIC MATRIX COMPOSITES HELD IN SEATTLE

The 5th International Conference on High-Temperature Ceramic Matrix Composites (HTCMC-5) will be co-located with the 56th Pacific Coast Regional and Basic Science Division Fall Meeting (PCRM) in Seattle, Wash., Sept. 12-16, 2004, at the Red Lion

Industry News

Hotel on Fifth Ave. To register or for more details visit, www.ceramics.org/htcmc5 or call 614/794-5890.

ALMATIS TODAY ANNOUNCES A WORLD-WIDE PRICE INCREASE FOR ALL SPECIALTY ALUMINA PRODUCTS

For all contracts effective on or after August 1st, Almatris will raise product prices by \$50-120/metric ton depending on product line. Almatris offers a complete portfolio of specialty alumina materials to the refractory, ceramics, polishing, specialty hydrate and adsorbents & catalysts markets.

“Over the past years our eleven global plants have worked hard on the reduction of manufacturing costs. However, worldwide demand growth has tightened supply of key materials such as alumina, and our energy and transportation costs have also escalated to an extent that additional cost pressures have exceeded our cost saving initiatives.” said Alex de Bonth, Almatris’ Chief Operations Officer.

Dr. Gangolf Kriechbaum, Chief Commercial Officer, adds “Our long-term focus on cost savings has allowed prices to be held very stable over many years. At the same time, we have made the necessary plant investments to have available for all our customers sufficient supply of our specialty alumina products. Almatris will continue to invest in our facilities and product development to assure our customers’ complete alumina needs are met.”

Almatris was formerly Alcoa World Chemicals and now operates as an independent global alumina materials company.

Contact: For Europe and Asia: Gabriele Drees, +49 69 95 73 41 44. For Americas: Marilyn Kunka, (412) 630-2809 or www.almatris.com

LASH PUBLICATIONS INTERNATIONAL WINS EIGHTH APEX AWARD

Lash Publications International is pleased to announce that it has received its eighth Award of Excellence from the APEX Awards for Publication Excellence. The award was received in the technical writing category for Virtual Building for Construction Projects, by Laurel M. Sheppard, published in the January/February 2004 issue of IEEE’s Computer Graphics and Applications magazine. The judges commented that the article displayed solid, well-structured writing and well-researched content. We liked the way that the functional captions tied the illustrations to the text. And we thought the sidebars showcasing related articles and links were especially useful. The writing category (both Feature and Technical) had a total of 884 entries. The panel of judges included John De Lellis, editor & publisher of Communications Concepts; Dr. Paul Fisher, Concepts senior evaluator and former professor of journalism at the University of Missouri School of Journalism; and Nancy Rathbun Scott, contributing editor of Writing that Works: The Business Communications Report.

Sponsored by Communications Concepts, publishers of business communication reports, including Writing That Works, this is the 16th year of the competition program, which had 5,462 entries in 11 major categories and 109 sub-categories. APEX 2004 awards were based on excellence in graphic design, editorial content and the success of the entry -- in the opinion of the judges -- in achieving

overall communications effectiveness and excellence. For further information, see <http://www.apexawards.com>.

Lash Publications International provides writing and editing services for a wide range of publications, including magazine articles, web sites, and newsletters. For further information, see <http://www.lashpublications.com>.


Laurel Sheppard is a contributing editor for *Refractories Applications and News*.

TAFT HONORS 26 OHIO COMPANIES FOR EXPORTING EXCELLENCE

Orrville-based The Will-burt Company Named 2004 Exporter of the Year

Columbus (June 24, 2004) Governor Bob Taft today presented 25 Ohio companies and organization with the Governor’s Excellence in Exporting Award (“E Award) and one Ohio business - The Will-Burt Company based in Orrville, Wayne County with the 2004 Exporter of the year Award.

“Ohio is an export leader in the highly competitive global economy,” Taft said. “The winners of this year’s ‘E’ Awards are setting a record pace by aggressively selling their products throughout the world.”

For more information contact: Jennifer Bartko or Bill Teets, ODO, at 614-466-4133; or Orest Holubec, Governor’s Office at 614-644-0957. 



Chuck Connors, Jr. of Magneco/Metrel, Inc.(Left) receiving the Governor’s Excellence in Exporting Award from Ohio Governor Bob Taft. June 24, 2004.

NEWS FROM THE WORLD REFRACTORIES CONGRESS (WRC'04)

Charles E. Semler, Semler Materials Services, Chandler, AZ 85248, E-mail: CESemler@aol.com



Charles E. Semler

The 2nd World Refractories Congress was held at the Singapore International Convention Center and Pan Pacific Hotel, June 27-29, 2004. There were about 200 attendees from 27 countries, with the largest delegation (~40) being from China. The two-day program, with the theme “New Challenges Ahead”, included 20 presentations, and no talks were cancelled. The meeting also included an exhibition, with 16 exhibitors from Australia, China (5), Germany (2), India (2), Italy,

Malaysia, Singapore, South Africa, UK, and Ukraine

INDUSTRY OVERVIEW

The keynote lecture was presented by Mr. A. Aranha, Corporate Director of Materials for ISPAT, International UK. Aranha emphasized the fact that China is dominating the world economy, and the steel industry in particular. However, there are signs that China's growth (GDP) may slow from 9.3% in 2003 to 8% in 2005. He stated that the key factors affecting the steel industry are the cost of environmental regulations, China's growth, intensified consolidation, economic slowdown in North American and Europe, and the entry of new EU members (with a migration of European steel-making to the East). As the quality of refractories has continually improved, the purchase/replacement demand has likewise continually decreased. The gradual increase in EAF steelmaking, with its lower refractory consumption rate, is also contributing to the reduced demand for refractories. The western refractory world is suffering from fierce cost competition, which is causing difficulty in competing with low-labor cost countries like China, India, and others, despite consolidation and permanent cost-cutting efforts. But there should be growth in refractory demand, at least through 2005. Aranha indicated that the refractories industry needs to further consolidate and globalize, provide more creative solutions, with emphasis on high value, more durable refractories, and to promote business partnerships and/or strategic alliances. He noted that the rules are changing, and “unless we change we stagnate, and if we stagnate we die”.

The writer presented a paper on “Key Issues for Today's Refractory Industry”, including U.S. issues (steel plant bankruptcies, refractory plant closures, globalization effects, Chinese imports, conformance to environmental standards, asbestos and silica litigation, and increasing costs). Other points discussed were improving profitability, increased refractory quality concerns,



Sign outside the WRC'04.

recycling, declining refractory education, and future refractory development. Historical data for steel and refractory production in selected countries around the world showed the rapid increase in China, with steel and refractories production up 74% and 51%, respectively, since 2000. By contrast, refractory production in U.S. and Japan has declined about 20% since 1998. Since 1999, refractory exports from China have increased from 350,000 to 825,000 metric tons in 2003. Increasing production of steel, cement, and aluminum worldwide indicate that there should be a positive effect on refractories business for at least the next 2-3 years. It must be remembered that the refractories industry plays a critical role, although silent and mostly unrecognized, in supporting all materials manufacturing by heavy industry around the world.

Mr. B. Gupta, Managing Director of Vesuvius India reviewed the prospects and challenges for the refractory industry. He noted that the migration of refractory manufacturing to China and Asia is accelerating. Closed plants from various places in the world are being dismantled and shipped to the Pacific Basin and Eastern Block. He advised more partnering ventures with customers, based on the development of more “smart” refractories, to promote win-win situations. And to further improve the performance of refractories, product design will play a more important role.

TECHNICAL INFORMATION

Prof. A. Yamaguchi of Japan discussed the “Development of Self-Repairing, Carbon-Containing Refractories”. The various additives to carbon-containing refractories serve to inhibit oxidation, but they also contribute to material development/deposition

in the structure, i.e., self-repair. The functions of additives Al_4O_4C , Al_2OC , and Al_4SiC were reviewed. Yamaguchi predicted that the development of new additives will result in improved carbon-containing refractories, with enhanced self-repair capabilities, although no examples of possible new additives were revealed.

Prof. R. Bradt, University of Alabama, USA, presented a tutorial lecture on "Spinel". Based on its good properties and the toxicity issues for refractories that develop Cr^{6+} in service, interest in spinel has increased greatly. It has a melting point higher than alumina, an attractive free energy of formation, and a structure that allows the accommodation of a diversity of cations, and impurities. Spinel can be formed from powder mixtures (including natural raw materials) by sintering, as low as $400^\circ C$, and by fusion above the melting point. Bradt considers that the usage of spinels, of various types, will continue to increase for a variety of refractory applications.

IRON AND STEEL INDUSTRY

Mr. K. Gruber of Voest-Alpine, Austria, discussed how to optimize the partnership between the plant builder and refractory industry for the benefit of the steelmaker. But he began by stating the fact that in 50 years the world steel production has quadrupled, while refractory consumption has been halved. Blast furnace lining life has increased from <10 years to >15 years, over the decades. He noted that refractory consumption for carbon steel production is 42 wt.% for ladles, 21% for blast furnace cast house, 20% for converters, and 7% for tundish/con-casting. He reviewed various developments in iron making, steelmaking, continuous casting, strip casting, automation, and sensor technology, and mentioned some of the refractory needs.

Ms. Li Tai of Baosteel Corp., Shanghai, China, reviewed their refractory situation, in which the refractory consumption was 9.3 kg/ton of steel in 2003. Their BOF converter life has reached 15,000 heats, but in 2003 averaged about 5000 heats, which is considered better for cost effectiveness and availability; the converter refractory consumption was 0.7 kg/ton of steel. Baosteel people say that high-class refractories make high-class steels, and they recognize the importance of the correct selection and adoption of refractories. To meet the demands of higher quality steels, they have conducted research on C-free ladle bottoms, low-C brick, and MgO-CaO refractories. They are also researching the recycling of refractories; e.g., 70% used MgO-C bricks added to MgO-C bricks.

OTHER TOPICS

Dr. N. Zhou from Henan University of Science & Technology, Luoyang, China, discussed refractory raw materials. He cited two main problems: (a) the quality and consistency is not reliable enough, and (b) the slow pace of development and commercialization of synthetic materials. He noted a big discovery of andalusite in Mongolia, the production of beneficiated/homogenized materials, and China's use of more CaO-enriched MgO instead of dolomite. Other materials of interest are fused materials with eutectic composition (alumina-zirconia and magnesia-zirconia) and dense or hollow synthetic balls (0.5-5 mm) with a smooth or rough/ridged surface, for a variety of applications.

Dr. N. Tsukamoto of Shinagawa Refractories discussed the current and future situation in Japan. Monolithic refractories account for 65% of their market; e.g., almost all >150 ton steel ladles are



A view of the Singapore skyline.

monolithic lined. He noted their emphasis on developing refractories that benefit their customers, such as using a 5000-ton vacuum press to make big blocks for the blast furnace and BOF. And they have developed a highly automated, robotized plant – the productivity of the plant is three times better than a normal plant, but the improved cost situation is still not as good as China.

Mr. K. Minoru of Krosaki Harima Refractories discussed the raw materials situation in Japan over the last 20 years. In 1980 the raw materials usage was 68% natural, 21% synthetic, and 11% recycled, compared with 52%, 41%, and 7% in 2002. He predicted an accelerated increase in high-grade and special steels in the coming decades, so there will be more stringent demands for more durable and reliable refractories.

There were talks on refractories for cement, glass, non-ferrous metals, and other topics, which are included in the Proceedings; contact: www.worldrefractories.com for information about the Proceedings.

The meeting ended with an open discussion based on video clips from Mr. Bill Brown, CEO of Resco Products, USA, Prof. Zhong Xiangchong of Zhengzhou University, China, and Mr. Nikolaus Kreuels, Chairman of the German Refractory Association. Brown focused on raw materials pricing and quality concerns, and also noted the fact that refractories are just a small cost of produced steel (<10%), so even if refractories were free, the steel industry would not realize a significant windfall. Brown emphasized that refractory companies need to work with their customers to show them how to reduce their costs. Prof. Zhong discussed refractory developments for the New Century. When asked if refractories technology has peaked, he answered "Definitely not"!! Important research areas include high quality synthetic raw materials and high quality functional refractories. He thinks that the refractories R&D in coming years should focus on oxide/non-oxide and free-lime-containing types (for steel-cleaning purposes), as well as castables. Kreuels reminded the audience that the refractories industry has suffered greatly in the last two decades, and now there are problems with raw materials and pricing. He mentioned that GRA is working to improve the reputation of the refractories industry, based on the need to enhance the commercial payback.

RAA

The Bookshelf

ACerS-NIST Phase Equilibria Diagrams CD-ROM Database

The Phase Equilibria Diagrams CD-ROM Database Version 3.0 contains approximately 20,000 diagrams previously published in 20 phase volumes produced as part of the ACerS-NIST Phase Equilibria Diagrams Program: Volumes I through XIII; Annuals 91, 92, and 93; High Tc Superconductors I & II; Zirconium & Zirconia Systems; and Electronic Ceramics I. Search capabilities allow searches by:

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- * Year (of original publication of the diagram)
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This new version offers full commentary text display in addition to diagram display. This makes the CD the same as the printed volumes with many additional features including high-quality printing and export capability. On-screen plotting can show any line types such as dotted, dash-dot, dash and solid. Files can be saved in both wmf and bitmap formats. Other features include:

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Refractory Lining Thermal Modeller

The Refractory Lining Thermal Modeller (RLTM) is a software program for rapid modelling of heat flows through furnace, heater and kiln linings. It is available for Mac OSX, Windows and Mac OS 8/9. Materials are dragged and dropped onto a lining model, and can be dragged to different positions and resized.


Material thicknesses, hot face and ambient temperatures, and environmental factors can be adjusted and are reflected live in the model window. Multiple resizable windows can be open at one time, so that potential linings can be compared. A sample is shown below.

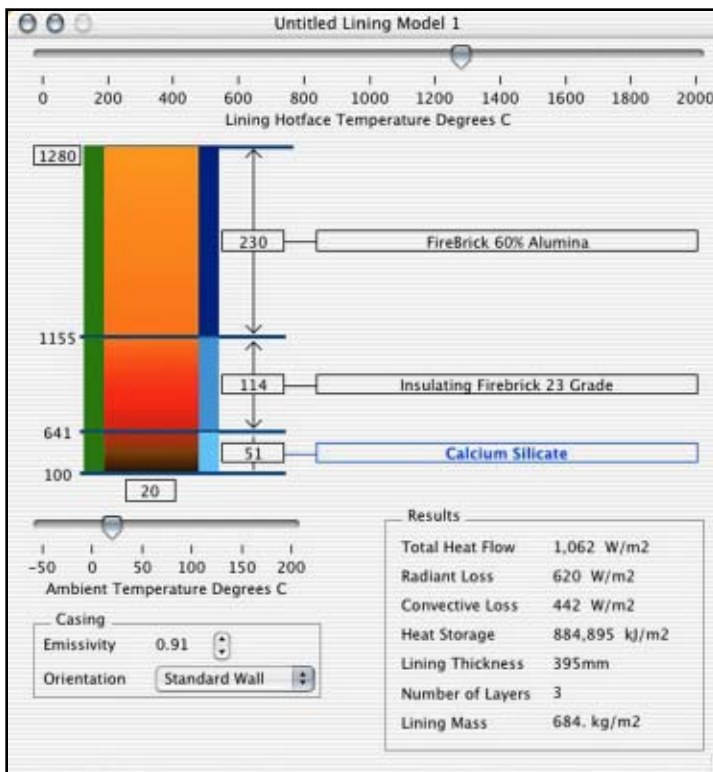
RLTM supports entry of materials in both ASTM and metric systems (or combinations), and produces results in either ASTM or metric.

Lining models can be printed out and saved to disk. RLTM includes a database structure to allow the easy addition and editing of lining materials.

Demo versions which are fully enabled when registered are available for download at the link below.

The download is approximately 2MB and includes a manual and sample database. The demo version is limited to use of the materials in the sample database, simple instructions for registration through PayPal are included.

See the following website for download: <http://www.hot-work.org/RLTM/RLTM.html> 



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REFRACTORIES FOR GASIFICATION REACTORS – A GASIFICATION TECHNOLOGY SUPPLIER'S POINT OF VIEW

Dirk Volkmann, Managing Director, Christian Reuther, Process Engineer, Dr. Tino Just, Process Engineer, FUTURE ENERGY GmbH, Halsbruecker, Strasse 34, 09599 Freiberg, Germany

1. FUTURE ENERGY GmbH, FREIBERG

FUTURE ENERGY GmbH is a German engineering company that owns proprietary pressure gasification technology including subsequent gas treatment for further use as synthesis or fuel gas, and undertakes to design and offer gasification-related plants.

The proprietary know-how developed by Deutsches Brennstoffinstitut Freiberg in the seventies was later advanced by Noell and Babcock Borsig Power, and has now been acquired by FUTURE ENERGY GmbH. Not only the professionals with long-term skills in the field of gasification, but also a complex of test facilities in Freiberg have been taken over by the new company.

The business of FUTURE ENERGY GmbH is focused on gasification of different types of feedstock to produce synthesis gas, electricity and process steam (Figure 1), which include:

- homogeneous and heterogeneous waste materials,
- chemical residues,
- renewable fuels (biomass)
- conventional fuels such as coal, liquid or gaseous fuel
- petroleum coke, heavy oil, distillation or hydrogenation residues.

As a provider of engineering services in the field of gas production, conditioning and utilization we offer:

- tailor-made burner solutions for most different gasification feeds (Figures 2 and 3)
- reactor/quench designs for different applications (Figures 4 and 5)
- feasibility studies
- plant expertise
- basic engineering packages
- plant commissioning and process optimization services
- construction supervision
- plant authorization and operating permit engineering
- mechanical design of special equipment.

Our test facilities are operated for research & development purposes covering the following subject areas:

- investigation of residual and waste materials with respect to gasification characteristics and yields
- input and output analytical by certified laboratories
- process and plant optimization studies to commercial scale

- development, fabrication and testing of new special-design burner solutions
- testing of new materials of construction
- expert advice on and evaluation of test results.

The heart of the entrained-flow gasification technology is a reactor that can be operated at pressures between 6 and 30 bar. The gasification feeds and oxygen required for the reaction are supplied through feed injectors on top of the reaction chamber.

Oxygen and organic matter of the gasification feeds are converted in a flame reaction at equilibrium temperatures ranging between 1400°C and 1700°C. The raw synthesis gas produced is mainly comprised of carbon monoxide and hydrogen, and does not contain hydrocarbons.

Noxious chlorinated organic substances as, for example, dioxins and furans are decomposed at high temperatures prevailing and the reducing reactor atmosphere, and their reformation is prevented by rapid cooling of the raw gas.

While passing the gas through further cooling stages, steam or hot water is produced. Noxious compounds that are typical of gasification such as H₂S, COS, HCN and NH₃ are separated by conventional gas cleaning and conditioning processes, and reusable elemental sulfur is extracted.

According to actual application requirements the cleaned gas that is free from volatile heavy metals and toxic organic constituents can then be utilized as a feedstock for chemical synthesis or as a fuel gas.

FUTURE ENERGY GmbH owns two patent reactor designs, the application of which is determined by the composition of the material to be gasified (Figures 4 and 5).

- Cooling Screen Reactor

Ash-containing (> 1 % by weight) feedstock is gasified in a reactor, the reaction chamber of which is enclosed by a tube screen of the membrane wall type that was designed to carry cooling water. With high-ash feedstock such cooling screen design ensures long service lives (10 years) at high gasifier availability. The mineral matter of the gasification feed melted in the gasification flame forms a slag film that flows down the cooling screen that is in turn protected by a thin layer of refractory ramming mass, and solidified inherent slag.

- Refractory-Lined Reactor

The reactor designed for gasification of ash-free or low-ash fuels (< 1 % by weight) is provided with a refractory lining that

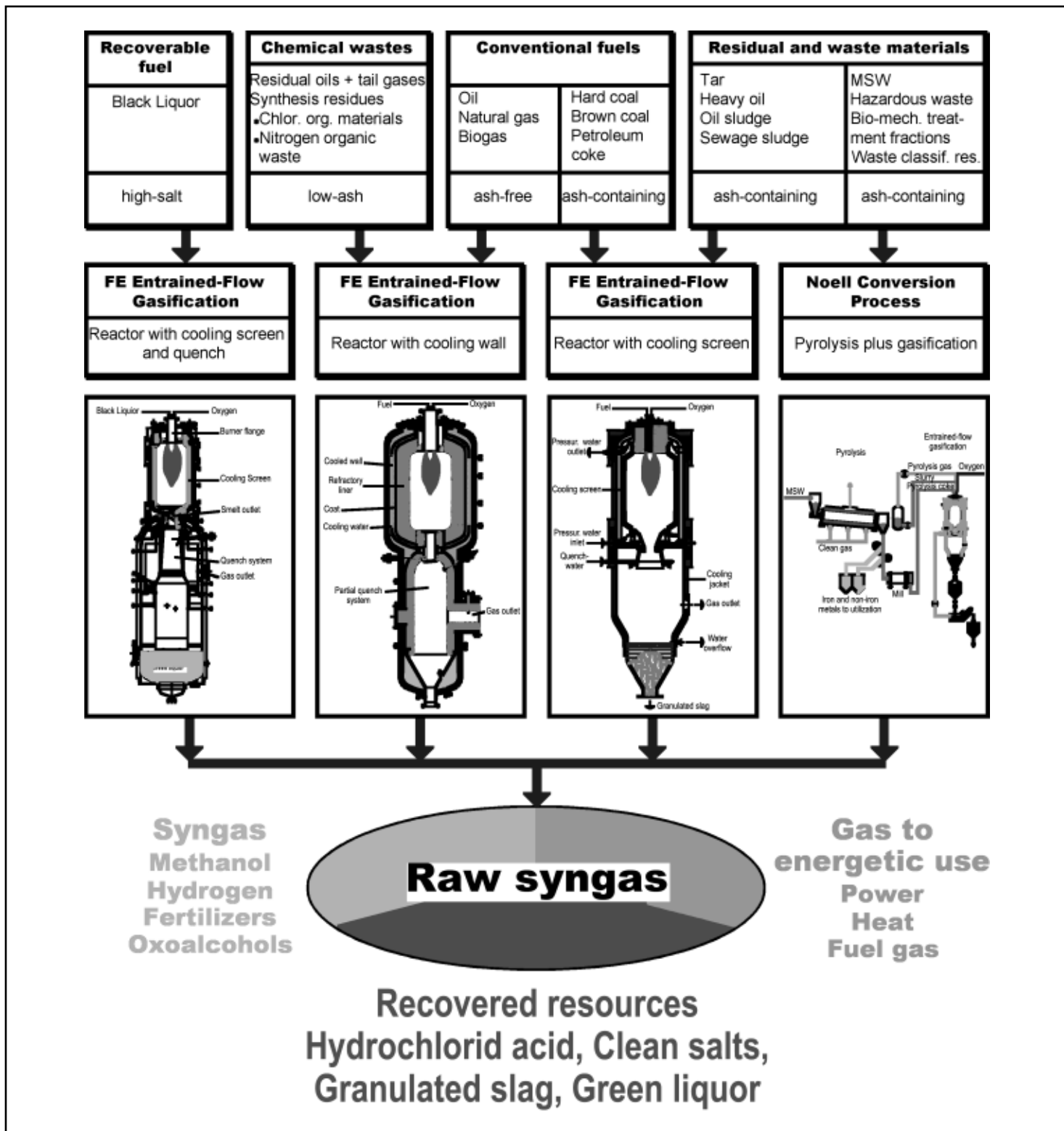


Figure 1. Gasification technologies of FUTURE ENERGY GmbH.

is shrouded by a cooled wall. The external pressure shell of the gasifier is protected by a water jacket that is also designed to carry away the heat flow passing through the refractory lining.

In case of fuel-ash induced erosion of the refractory, solidifying slag ensures reliable protection from hot spots. This design solution combines the experience gathered with cooling screen and refractory-lined systems.

The reactors of both design variants can be combined with either a total quench system or a heat recovery partial quench system, or can be equipped with a radiant heat exchanger.

The test facilities of FUTURE ENERGY GmbH in Freiberg are used to develop prototype designs and to test new or advanced equipment, or gasification feeds of most different provenance. The facilities can be modified to enlarge the variety

of candidate gasification feeds and to perfect the technology as such.

The test facilities are licensed for the gasification of a wide feedstock variety, so that there is no special permit required to conduct trial campaigns.

The size of the test facilities enables reliable scale-up to commercial plant scale.

The test facility complex comprises:

- two gasification reactors for low-ash and high-ash feedstock with thermal capacities of 2 - 3 MW and 5 MW at gasification pressures of 6 to 26 bar
- catalytic COS and HCN hydrolysis unit
- SulFerox desulfurization system
- waste water treatment system including, among others, heavy metal precipitation
- NH₃ stripper
- diverse conveying, dosing and feeding systems for pulverized and liquid gasification feeds and slurries
- utilities supply systems for oxygen, natural gas, inert gas at supply pressures of up to 100 bar.
- BOP for both reactors.

a) Demonstration and test facility 5 MWth:

- Thermal output: 5 MW ca. 300 - 500 kg/h of gasification feed (dependent on heating value)
- Commissioned: 1996/97
- Reactor type: cooling screen reactor with total quench system
- Gasification pressure: 6 to 26 bar
- Feedstock: liquid (pumpable) or solid (pulverized) contaminated residues with ash contents of up to 40 wt.%.

b) Test facility 3 MWth (VV 100):

- Thermal output: 3 MW ca. 150 - 300 kg/h of gasification feed (dependent on heating value)
- Commissioned: 1979
- Reactor type: refractory-lined with total quench system
- Gasification pressure: 6 to 26 bar
- Feedstock: liquid (pumpable) or solid (pulverized) contaminated ash-free or low-ash residues.

2. Previous Black Liquor Gasification Experience

The Freiberg pilot reactor (cooling screen design) previously designed for coal was used for black liquor gasification testing. There is a

big difference between coal slag and the salts arising as mineral residue in black liquor gasification processes. Notwithstanding a theoretical melting point of about 750°C, the actual melting temperature can vary in a range of 400°C to 780°C depending on the composition of the gasification feed, because the components form a eutectic mixture. The measured maximum heat flux amounted to 270 kW/m².

Under those conditions the hot face temperature of a SiC layer of some 13 mm in thickness comes up to about 440°C at a cooling water temperature of 70°C (respectively to 723°C at a cooling water temperature of 250°C), i.e. the solidified salt layer growing on the refractory will just reach a thickness of 0.8 mm (or 0.1 mm respectively).

Furthermore, the viscosity of the smelt is lower than that of coal slag by a factor of 1000, so that best conditions are given for a transfer of mass into the SiC layer and its spalling due to chemical reactions.

Pieces of the acidic bond refractory were found during the tests in the smelt flow. The duration of the tests, however, was not long enough to establish equilibrium conditions and to find out, if and when this process came to a stop.

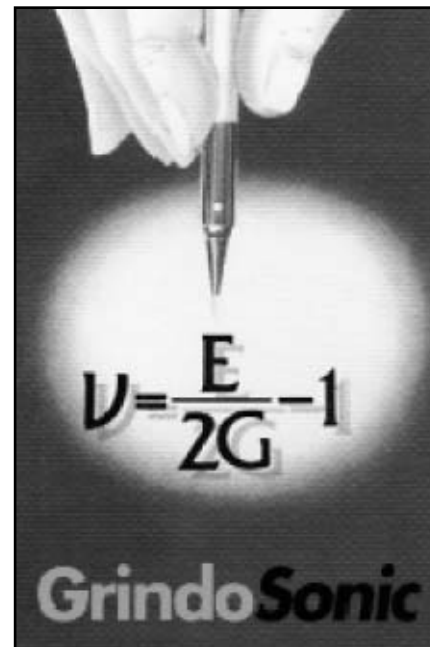
Simulation results imply that the formation of a solidified salt layer is not given with SiC layer thicknesses of greater than 13 mm.

The question, if a salt layer of less than 1 mm in thickness is capable of shielding the SiC layer under unsteady operating conditions (varying salt melting point, fluctuating gasification temperatures) is still open.

3. Bench Testing of Cooled Specimens

In order to simulate the conditions of a ceramic lined cooling screen, bench tests were carried out with a simple test setup allowing to test refractory masses without great expense for their applicability as cooling screen ramming masses. The tests primarily focussed on ramming masses, because those can easily be applied to specimens.

The test setup consisted of an electrically heated muffle furnace designed to accommodate in its upper part a crucible with black liquor salts. Through an opening in the cover brick of the muffle furnace it was possible to insert into the crucible a dou-



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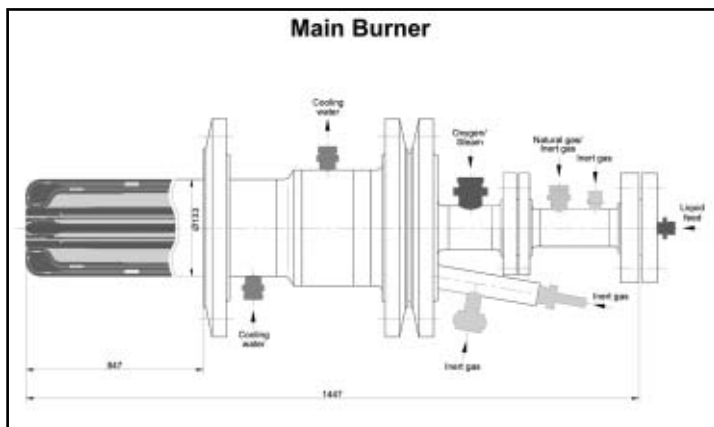


Figure 2. Main burner design (coal dust-, liquid atomization burner).

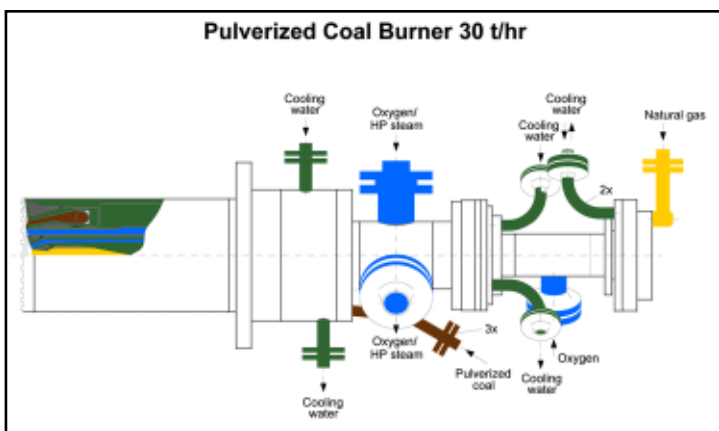


Figure 3. Pulverized coal burner design (coal dust, liquid atomization burner).

ble-wall tube that was cooled on the inside and provided with a ramming mass coating on the outside.

When heating the muffle furnace to some 900°C, the salts in the crucible melt and make contact with the ramming mass. The heated furnace was furthermore charged with a mixture of H₂/N₂ to create a reducing furnace atmosphere.

By coolant flow and temperature difference measurement during the tests there was the ability to specify the heat input into the cooling medium. After test completion the appearance of each of the ramming masses was inspected with a view to chemical attack implications.

In a first series of 24-hour-tests, a total of 25 refractory grades were screened, namely with

- excellent heat conductivity – thin metal coatings
- good heat conductivity – materials rich in SiC
- medium and poor heat conductivity - Al₂O₃, MgO and chrome-magnesite mixes of different composition.

Each time a cooled ramming mix-coated finger specimen was tested in the smelt together with an uncooled one. At this stage the materials already showed differences in quality, wherefore only 12 materials were selected for a second test series over 100 hours.

As a result of the aforementioned tests a significant difference between cooled and uncooled specimens became apparent. Whereas most of the uncooled specimens “vanished” in the course of the tests,

the cooled specimens showed only minor defects, an aspect that corroborated the theory.

In a last test series, specimens were exposed to the smelt for 500 hours. Subsequently, however, the tests were cut short, since further tests would have required new and better test appliances as well as specific R&D effort, the scope and expense of which would have gone beyond the means of a single plant engineering company.

4. Demands on Refractories for Black Liquor

Gasifiers

In pulping operations Black Liquor is obtained, a major renewable by-product stream that contains Na₂CO₃, NaOH and Na₂S as well as organic substances. So far this spent liquor was commonly burnt in recovery boilers under substoichiometric conditions using the organic matter for power generation. Molten alkaline salts were recovered and reused in the kraft pulping process.

Emerging technologies for the gasification of black liquor have the potential to replace recovery boilers significantly improving overall pulping economy, as well as relevant environmental and safety advantages for the kraft process. Since operating efficiencies compared to recovery boiler operations will significantly increase, electricity generation can be doubled and the heat export increased.

This was the driving force for FUTURE ENERGY GmbH to develop an oxygen-blown pressure gasification technology for black liquor. The special-design reaction chamber of this black liquor gasifier is encased by a water-cooled tube screen that is coated with a ceramic liner designed to protect the bare metal surface of the tube against the chemical attack of the salt smelt, and to limit the heat transfer into the cooling screen.

From previous recovery boiler operating experience refractory stability and lifetime problems are generally known. Process conditions require the cooling screen refractory lining material to meet the following demands:

- Resistance of the refractory to the attack of the salt smelt with major components Na₂CO₃, Na₂S, NaOH and minor components SiO₂, NaCl, KCl
- Resistance of the refractory to the attack of gaseous reaction products, i.e. reducing components H₂, CO oxidizing components H₂O, CO₂, and secondary components H₂S, COS, NH₃, HCN, HCl, Na and NaOH vapors, soot, char particles, aerosols of liquid slag constituents
- Resistance of the refractory to the above forms of attack to be ensured under gasification conditions: pressure up to 40 bar and reaction chamber temperature 950 - 1400°C, where temperatures are highest in the area of direct flame impingement.

By experience, the resistance of the refractory material under the conditions described above can be achieved using the following three approaches:

- Application of a refractory material that is absolutely resistant to reaction conditions and also meets the under mentioned premises.

With such material available, the use of an uncooled refractory-lined reactor would be appropriate.

If a refractory conserves the desired properties just up to a defined upper temperature limit, exceeding the temperature

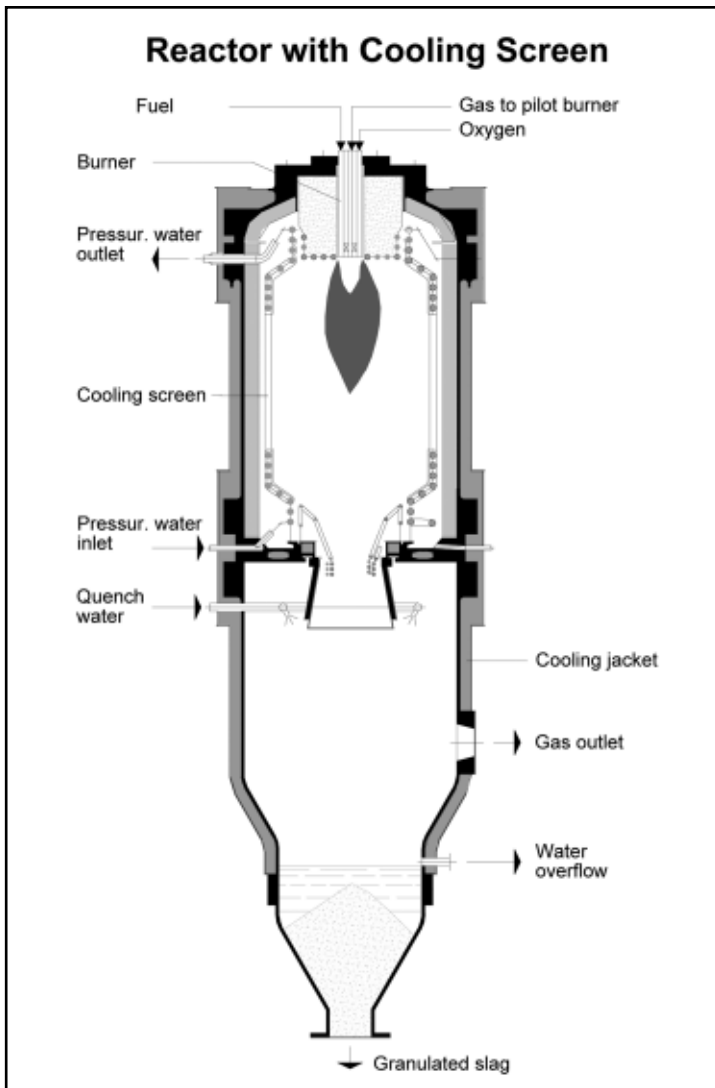


Figure 4. Reactor design with cooling screen.

threshold must be prevented, demanding the material meet specific thermal conduction requirements.

- Application of a refractory that will seal the exposed hot face surface as a result of chemical reactions with the salt smelt and salt impregnation, and this way protect the rest of the liner against further attack. Thereby the refractory lining must be cooled to the extent required to preserve the resistance of the protective layer.
- Application of a refractory material in combination with a highly efficient cooling system so as to allow a sufficiently stable layer of solidified salt smelt to build up on the refractory lining even in cycling operation, which protects the refractory lining against further salt impregnation and chemical attack. This goal can only be attained if high heat flux densities can be realized with a refractory of excellent thermal conductivity.

Thereby the heat flux through the reaction chamber wall should be as low as possible to keep heat losses of the reaction chamber down, but high enough for the required stability of the refractory material.

In addition to the aforementioned major demands there are further requirements to be fulfilled as specified below:

- Resistance to thermal shock during plant start-up and shutdown operations

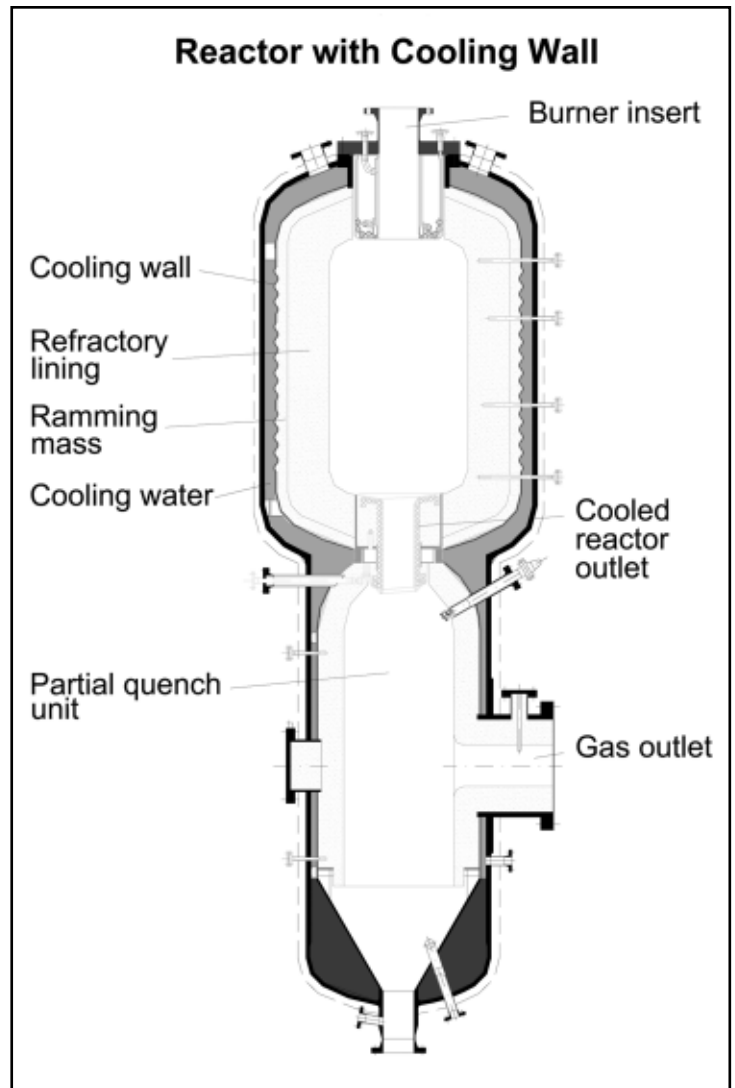


Figure 5. Reactor design with cooling wall.

Whereas a temperature-time regime can in a way be realized in the course of plant start-up, the cooling rates during shut-down operations are determined by the cooling system and the thermodynamic characteristics of the refractory material.

With a combined cooling screen and refractory design cooling rates are supposed to come up to 100 – 300°C/min requiring the thermal expansion coefficients of refractory and cooling screen materials to be aligned.

- Resistance to reactor gas pressure fluctuations
During shutdown operations, in particular, the rate of pressure drop can come up to 5 - 10 bar/min after plant depressurization has started.
- Firm and durable bond between refractory and cooling screen material to ensure the required cooling effect
Crevices between cooling screen and refractory lining need to be avoided.
- Ease of application
The cooling screen lining shall be capable of being reproduced at controlled quality. A repair technology for local damages shall be available.
- Resistance of the refractory liner or of the sealing layer formed as a result of refractory reactions with smelt compo-

nents to secondary influences during start-up or shutdown operations, or to atmospheric moisture in downtimes

Steam condensation caused by temperatures on and within the refractory lining falling short of dew point temperature is excluded by operating the cooling screen in every phase of operation at temperatures well above the dew point.

- Cooling water side temperatures can come to 250°C maximum.

At given thermal conductivity and refractory lining thickness a ceramic bond of the refractory applied to the cooling screen is not feasible, because the temperatures required for this cannot be reached.

5. Summary and Outlook

The tests described in this paper were primarily aimed to define and verify refractory R&D trends. The R&D activities were then provisionally ceased, because we as a plant engineering company in the field of pressure gasification were lacking certain prerequisites to carry on R&D work in the field of ceramic materials sciences.

Due to the relevance of this assignment we are, however, still looking for an opportunity to combine our technology experience with that one of a major partner in ceramic materials sciences to answer this challenge and to develop advanced solutions. **RAM**

ASTM COMMITTEE C08, REFRATORIES

The American Society for Testing Materials International (ASTM) Committee C8 is continuing its work in developing and maintaining standards for the refractories industry. This committee meets twice per year, usually in conjunction with other industry meetings and activities. The committee met in late 2003 in Tampa, and then met again in St. Louis last spring in conjunction with the St. Louis Section of the American Ceramic Society. Membership is offered to and encouraged for those interested in refractories. More information can be obtained by visiting the ASTM website at www.astm.org.

There are literally hundreds of standard methods, standard practices, and standard classifications which fall under C8's supervision. The Committee is subdivided into 10 Subcommittees, each Subcommittee having its own area of expertise. New standards are developed, and old standards are reviewed, at every meeting. Between meetings, electronic communications have facilitated the drafting and refining of documents being considered.

C8 will meet this October in Washington, D. C., for its 185th meeting. If you are interested in refractory production or applications, consider attending a meeting of C8. You'll at least find out what the difference is between a standard test and a standard practice.

Adam Holterhoff
Secretary C8

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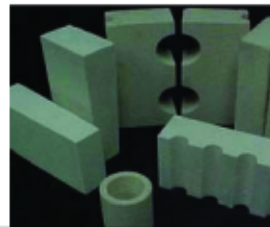
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REFRACTORY RESEARCH GROUP – U.S. DOE, ALBANY RESEARCH CENTER

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The refractory research group at the Albany Research Center (ARC) has a long history of conducting materials research within the U.S. Bureau of Mines, and more recently, within the U.S. Dept. of Energy. When under the U.S. Bureau of Mines, research was driven by national needs to develop substitute materials and to conserve raw materials. This mission was accomplished by improving refractory material properties and/or by recycling refractories using critical and strategic materials. Currently, as a U.S. Dept of Energy Fossil Energy field site, research is driven primarily by the need to assist DOE in meeting its vision to develop economically and environmentally viable technologies for the production of electricity from fossil fuels. Research at ARC impacts this vision by:

- Providing information on the performance characteristics of materials being specified for the current generation of power systems;
- Developing cost-effective, high performance materials for inclusion in the next generation of fossil power systems; and
- Solving environmental emission and waste problems related to fossil energy systems.

A brief history of past refractory research within the U.S. Bureau of Mines, the current refractory research at ARC, and the equipment and capabilities used to conduct refractory research at ARC will be discussed in the following sections.

HISTORICAL RESEARCH IN USBM

Refractory research at the Albany Research Center (ARC) has a history dating back to its inception in 1911 within the U.S. Bureau of Mines, Department of Interior, at Ohio State University. Its first research publication on “Mining and Treatment of Feldspar and Kaolin” was published in 1913, and established a long history of service to the industry and to the Nation in ceramic research. Through the years, refractory related-research moved from location to location, existing at Seattle, WA; Norris, TN; College Park, MD; and Salt Lake City, UT, where refractory research was conducted changed with the organizational goals of the Bureau. In 1971, all refractory and ceramic programs were centralized at Tuscaloosa, AL, which became the direct descendent of the current program in Albany, OR. With the reorganization, and later closure of the U.S. Bureau of Mines in 1995, refractory research was consolidated at the Albany Research Center and was transferred to the U.S. Dept. of Energy’s Office of Fossil Energy, where it currently resides. The Albany Research Center and its location in Albany, Oregon, are shown in Figure 1.

Throughout its history in the Bureau of Mines and in the Dept. of Energy, research was always driven by the realization that pyrometallurgical industries such as foundries and the industries processing materials such as steel, copper, zinc, lead, aluminum, cement, and glass could not exist without refractories and the major raw materials for their production, namely refractory grade bauxite, chrome ore, magne-



Figure 1. The Albany Research Center main building.



Figure 2. Location of the center.

sia, and natural flake graphite, minerals which are often imported. Research centered on identifying substitute materials and/or conserving raw materials by improving service life and by recycling refractories. These needs were most evident for materials identified as critical and/or strategic, and were the driving force for all early research. During World War I, the Bureau’s ceramic research resulted in technically significant contributions in developing clay-graphite crucibles, domestic

Table 1. Research Projects Conducted at the Tuscaloosa Research Center from 1972-1995.

<u>Year of Project</u>	<u>Research Goal</u>
1972-1986	Evaluation of natural clays for commercial applications
1975-1982	Determination of refractories for high pressure, high temperature dry ash coal gasifiers
1978-1982	Recycling chrome oxide containing refractories
1979-1988	Evaluation of chemical resistant masonry – resistance to HCL, HNO ₃ , and H ₂ SO ₄ acid environments and moisture expansion
1982-1988	Crucibles for molten glass containment
1982-1988	Improving the corrosion resistance of periclase and alumina refractories through additives
1983-1989	Characterization of the role of natural flake graphite in dolomite/carbon refractories
1986-1988	Refractories for aluminum furnaces – corundum growth
1989-1995	Advanced refractory materials – focus on the synthesis of Al ₄ O ₄ C and on the intercalation of clay to form SiC, AlN, SiAlON and Si ₃ N ₄
1992-1995	High temperature acid attack of refractory ceramics

Table 2. Main program areas for refractory research conducted at the Albany Research Center from 1995 to 2004.

<u>Program Area</u>	<u>Research Goal</u>
1	Recycling/reuse of spent refractory materials
2	Improving the refractory service life of refractory materials used in electric arc steel production
3	Improving the service life of refractory liner materials and of thermocouples used in integrated gasification combined cycle slagging gasifiers

clays for pottery, and refractories for the metallurgical industries. More recent significant research included the characterization of domestic and foreign clays for applications ranging from structural clay products to refractories, the development of a way to separate kaolin clay flocks and to process them into finer particle sizes, and the determination of refractory liner materials in proposed dry-ash lining systems for high BTU coal gasification processes. A listing of refractory research conducted at the Tuscaloosa Research Center of the US Bureau of Mines is listed in Table 1. At peak employment in Tuscaloosa, approximately 5 professionals and 6 technicians conducted refractory research, not including center support help for analytical work.

CURRENT RESEARCH AT ARC

The movement of program research from the Tuscaloosa Research Center in Tuscaloosa, AL under the U.S. Bureau of Mines to the Albany Research Center in Albany, OR, brought about changes not only in personnel and funding, but also in program direction. The Albany Research Center is composed of approximately 85 full time employees and is divided into three research groups conducting materials related research. These groups are the Office of Materials Development, the Office of Materials Performance, and the Office of Process Development. The refractory research team falls under the Office of Material Performance and is currently composed of one supervisor, 4 professionals, 1 technician, and other assistance from the research center on a team-work basis. Refractory research has concentrated into three areas during its nine year history at Albany, as is shown in Table 2. The focus of refractory work follows:

1. Recycling/reuse of spent refractory materials – The goal of the recycling/reusing spent refractory material research was

to encourage producers, users, recyclers, or other companies to reuse spent refractory material. A number of driving forces exist to encourage recycling, including landfill space and cost as well as a growing concern over legislation, the environment, and future liability of spent refractory material. The ARC worked directly with several primary aluminum producers (Alcoa and Kaiser Aluminum Co.), electric arc steel producers (through the Steel Manufacturers Association), and a number of individual companies (such as in the brass and lead industries) to reuse/recycle spent refractory material. Over 98 % spent refractory was recycled at one aluminum producer. ARC developed technology to reuse basic refractory linings as slag conditioners in electric arc steel mills.

2. Improving the service life of refractory materials used in EAF steel production – The goal of research to extend the service life of EAF refractories was to make slag chemistry compatible with refractory materials and formulated for ideal slag foaming. This work was conducted in collaboration with Baker Refractories (now LWB Refractories), Martin Marietta Magnesia Specialties (business sold to Minteq Intl., Inc.), and over 20 members of the Steel Manufacturers Association. Through better control of slag chemistry and slag foaming practices in a EAF; longer refractory life, lower energy consumption per ton of steel produced, lower emissions, and greater on-line availability of the EAF is achieved.
3. Improved liner materials for gasification systems – The goal of research to extend the service life of liner materials used in slagging gasifier systems that produce chemicals and power is to increase their on-line availability. Research



a.



b.



c.



d.

Table 3. Specialized refractory test capabilities.

- Rotary slag testing (oxidizing and reducing atmosphere to 1500°C)
- Inductively heated air/slag/metal testing (+1650°C)
- Thermal expansion under load (1550°C)
- Slag drip furnace under controlled atmosphere (1500°C)
- Hot modulus of rupture (1500°C in air or controlled atmosphere)
- High temperature TGA, DSC exists up to 1500°C in controlled atmosphere
- High temperature TGA (samples up to 100 grams, controlled atmosphere, up to 1600°C)
- Slag cup testing (controlled atmosphere up to 1600°C)
- Sessile drop test (controlled atmosphere up to 1250°C)
- Rotary pencil testing (up to 1600°C)
- High temperature abrasion

EQUIPMENT AND ANALYTICAL CAPABILITIES

Major equipment for chemical and physical property characterization available at ARC is listed in Table 3. Most testing equipment is run according to ASTM International procedures, but many tests are modified for specific testing under desired test conditions. Specialized equipment for slag testing is shown in Figure 3, and includes air/slag/metal testing, cup tests, slag drip tests, and the rotary slag test. Slag evaluation equipment is heavily utilized in current programs. Techniques for the standard characterization of materials for density, porosity, room temperature crushing strength, oxidation resistance, hydration resistance, reheat expansion, particle size, room temperature Young's modulus, and other properties are available. Sample preparation equipment includes high intensity mixers, presses, extruders, dryers, and controlled humidity ovens. Furnace capabilities range from inductively heated furnaces to gas and electric furnaces, many with controlled atmosphere capabilities. Mineral beneficiation equipment includes crushers, screens, attrition mills, and rod and ball mills. Materials can be calcined in a rotary furnace, sintered, arc or inductively fused, or chemically produced. A variety of saws and core drills exist for sample preparation. The evaluation of a sample's microstructure can be done by XRD, X-ray fluorescence, optical microscopy, SEM, or TEM. SEM capabilities include fluorescence and backscatter imaging as well as chemical analysis by wavelength on energy dispersive spectroscopy. Chemical analysis is typically conducted by wet chemistry or atomic absorption, but may involve other techniques as needed.


Other facilities exist at ARC for possible sample exposure or large scale testing, and include EAF furnaces from 50 to 2400 lb capacity, an 18 in ID cupola, a 2000 lb aluminum reverberatory furnace, and vacuum and air induction furnaces up to 300 lb capacity. Additional information on the Albany Research Center and its capabilities are available at the following Website: www.alrc.doe.gov, by phone at 541-967-5862, or by writing: U.S. DOE - Albany Research Center, 1450 Queen Ave. SW, Albany, OR, USA, 97321. 

Figure 3. Test equipment to evaluate the slag resistance of refractory materials: a) slag drip furnace, b) rotary slag furnace, c) air/slag/metal testing, and d) cup testing.

is focused in two areas: improving high chrome oxide based refractory liners and developing non-chrome oxide liner materials. Plant trials are underway at a number of gasifier users to evaluate materials developed at ARC.

RESEARCH MECHANISMS

Refractory and other types of material research at ARC are most often conducted through agreements with private industry, such as using a Cooperative Research and Development Agreement (CRADA), a Reimbursable Funds-In Agreement, and a Non-Disclosure Agreement for evaluating proprietary data. Direct involvement with industry helps ensure a real-world basis for research conducted at Albany.

REFRACTORY LINER MATERIALS USED IN SLAGGING GASIFIERS

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ABSTRACT

Refractory liners are used on the working face of entrained-flow slagging gasifiers that react coal, petroleum coke, or other carbon feedstock with oxygen and water. The refractory liners protect the gasifier shell from elevated temperatures, corrosive slags, and thermal cycling during gasification. Refractory failure is primarily by two means, corrosive dissolution and spalling. High chrome oxide refractory materials have evolved as the material of choice to line the hot face of gasifiers, yet the performance of these materials does not meet the service requirements of industry. A review of gasifier liner materials, their evolution, issues impacting their performance, and future research direction are discussed.

Keywords: Gasifiers, Slagging gasifiers, Chrome oxide refractories, Coal slag, Petroleum coke slag, Slag corrosion, Spalling

INTRODUCTION

Gasifiers are used to produce power and chemicals used in other industrial processes. A gasifier acts as a containment vessel to react liquid fuels, a carbon source (coal and petroleum coke are the most commonly used), water, and oxygen at elevated temperatures and under reducing conditions; producing CO and H₂, as the primary gases, along with CO₂, CH₄, HS and other trace gases. Gasifiers fall into one of three varieties: fluidized-bed, moving-bed, or entrained-flow systems; with only the entrained-flow gasifier producing a fluid ash (slag) from impurities in the carbon source, the other two gasifier varieties producing a “dry” ash by-product. In an entrained-flow gasifier, the bulk of this molten slag flows down the gasifier sidewalls, with only minor amounts associated with the excess carbon and existing as fused particles. Slag is considered one of the primary by-products of the gasification process, varying greatly in chemistry and quantity depending on the gasifier feedstock and operation conditions. A coal slag typically contains SiO₂, FeO, CaO, and Al₂O₃; with vanadium oxides also present in a petroleum coke slag. Slag quantities in excess of five or more tons per hour can be generated in a gasifier, depending on the carbon source, the quantity of impurities present in it, and gasifier throughput. The ability of a slag to flow and to cause predictable refractory wear in an entrained-flow system is critical to its operation. Industrial and government interest in gasifiers has varied over time, driven by high energy prices, perceived/real shortages of energy producing raw materials, efficiency of the gasification process, low water consumption compared to other processes, and the ability of a gasifier to generate very low levels of pollutants. The low

level of pollutants is achievable because gasification is a controllable closed circuit process that has been designed to produce low levels of NO_x, and because other low level emissions such as sulfur and mercury from the gasification process can be captured and/or processed for reuse as by-products. Research is underway to sequester and/or find uses for CO₂, a future environmental concern and a thermodynamic by-product of the gasification process that is easily captured.

The gasification chamber of an entrained-flow gasifier typically operates at temperatures between 1250° and 1550°C, at pressures of 400 psi or higher, and is lined with refractory materials to contain the severe environment and to protect the outer steel shell from erosion, corrosion, and high temperature. As mentioned, the slag is liquefied in the gasification chamber, and can corrode, penetrate, and react with the refractory liner at elevated temperatures, severely limiting refractory service life and gasifier operation. Two types of entrained-flow gasifiers are used in industry, water cooled and air cooled. Water cooled gasifiers have a working face lining of Al₂O₃-SiC refractory, and have a satisfactory service life because slag freezes on the refractory surface, restricting slag penetration and corrosion. The long refractory service life of the water cooled design comes at a performance cost, with slightly lower energy efficiency versus an air cooled design. Air cooled entrained-flow gasifiers are lined with refractory materials found to give the best service life and on-line performance – a high chrome oxide material that contains alumina and may contain other additives like zirconia. Refractory liners in an air cooled entrained-flow gasifier last anywhere from three

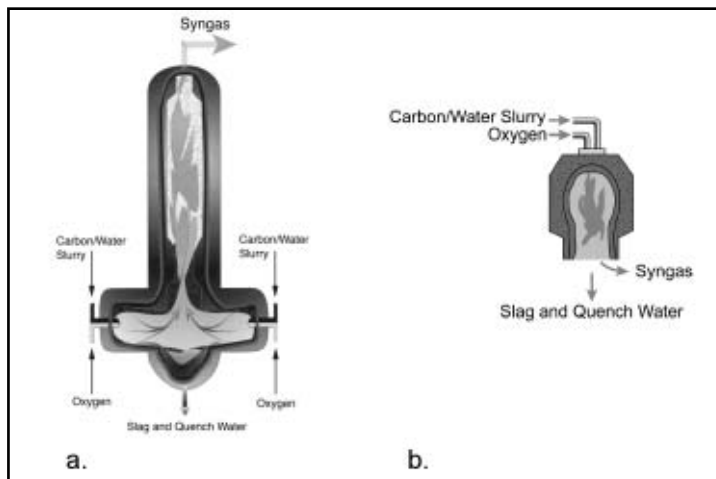


Figure 1. Two types of commercial entrained-flow slagging gasifier designs; a) opposing flow burner, and b) single burner.

months to two and one-half years. Cross sections of two types of air cooled entrained-flow gasification chambers used in industry are shown in Figure 1. These gasification chambers can be up to approximately 82 feet in length and 16 feet in diameter [1]. In spite of the superior performance of chrome oxide based refractory liners over other material, gasifier operators and designers using air cooled systems have identified refractory service life as the most important factor limiting their on-line availability [2]. This paper will review refractory liner materials currently used in gasifiers and their evolution, analyze failed refractory materials, and discuss trends in future refractory research for gasifiers.

REFRACTORY MATERIALS USED IN GASIFIERS AND THEIR EVOLUTION

Because of the severe environment in an air cooled entrained-flow slagging gasifier, the material challenges for a refractory liner are many, and include: elevated temperature; large and/or rapid changes in temperature; erosion by particulates; molten slag attack; variable slag composition resulting from the feed stock; attack by hot corrosive gases; alkali vapor attack; and variable oxidizing and/or reducing conditions [3-5]. Refractory materials that can withstand these environments for long periods of time are necessary for a continuous, efficient, and reliable gasification process. A number of refractory compositions have been evaluated historically in these harsh thermal environments; and include sintered and/or fused cast alumina-silicate, high alumina, chromia-alumina, chrome-magnesia spinels, alumina and magnesia, alumina and chrome, and SiC refractory compositions [6-10]. Thermodynamic and phase diagram studies must be taken into account when choosing the composition of hot face or of backup refractory materials. Compounds like Fe_2O_3 and SiO_2 can form reactions with CO , H_2 , or H_2O in the gasifier environment as follows:

1. $2\text{CO} \rightarrow \text{CO}_2 + \text{C}$ (in presence of Fe_2O_3 , $T \sim 570^\circ\text{C}$) [11]
2. $\text{SiO}_2 + \text{H}_2 \rightarrow \text{H}_2\text{O} + \text{SiO}\uparrow$ [11]
3. $2\text{SiO}_2 + 3\text{H}_2\text{O} \rightarrow \text{Si}_2\text{O}(\text{OH})_6\uparrow$ [12]

These and other gasification reactions are possible or have been theorized [1, 11-14] to occur on either the surface or within a gasifier refractory (due to the thermal gradient). Caution must be taken to minimize possible gaseous interactions; such as with CO , H_2 , or H_2O ; by controlling refractory components. Wear by corrosion was evaluated and noted in refractory materials containing high levels of Al_2O_3 or $\text{MgO}/\text{Al}_2\text{O}_3$ spinels during simulated gasifier environment testing using a synthetic coal type slag [6-9]. Other refractory materials, like SiC or Si_3N_4 , were found to react with components in the slag, causing severe material wear. SiC, for instance, interacts with FeO in the slag, yielding volatile gases (CO , SiO and/or others) and metallic iron. Fuse cast refractory materials with little or no porosity often had low chemical wear, but suffered from thermal shock, a threat to refractories because of constant gasifier shutdowns.

In general, chrome oxide additions to a refractory composition were found to improve their slag resistance. The high chrome oxide material used in most slagging gasifiers today has its roots in DOE and Electric Power Research Institute

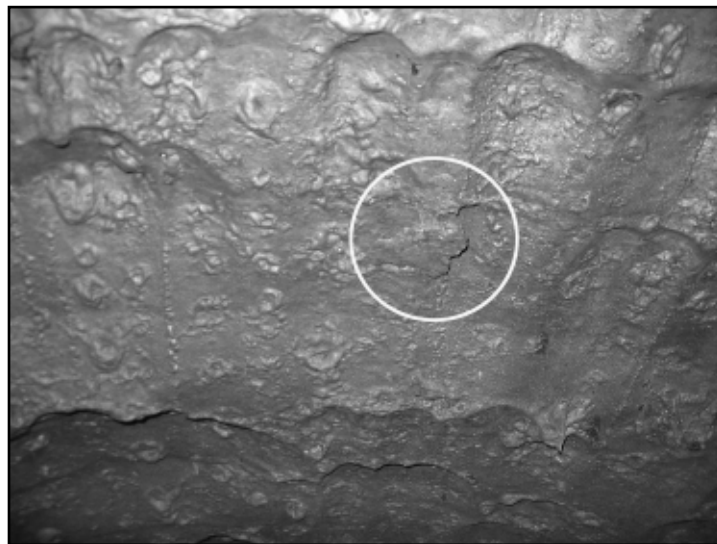


Figure 2. Hot face of high chrome oxide refractory material in a slagging gasifier (spalled refractory material circled).

(EPRI) funded efforts traceable back to the 70's and 80's [3-9, 13, 15]. Research and industrial experience indicated that only $\text{Cr}_2\text{O}_3 - \text{Al}_2\text{O}_3$, $\text{Cr}_2\text{O}_3 - \text{Al}_2\text{O}_3 - \text{ZrO}_2$, and $\text{Cr}_2\text{O}_3 - \text{MgO}$ compositions could withstand gasifier environments long enough to be economically feasible [3, 10, 14]. A strong desire has always existed in industry to develop an improved performance refractory with a low cost. Bakker [16] indicated that a minimum Cr_2O_3 level of 75 wt.% is necessary in a refractory material for sustained material performance in slagging gasifiers. One problem in evaluating materials is that good tests simulating the gasifier environment do not exist, making it difficult to equate laboratory results with material performance in industry. Taber [1] discusses general factors to take into account when choosing a gasifier refractory, including chemical compatibility, thermal and mechanical concerns, and design issues.

The failure of a refractory lining in a gasifier is expensive, both in terms of the refractory replacement costs (as high as one million USD, depending on gasifier size and the extent of rebuild required), but also in lost production down time. Relining a gasifier requires that the system be completely shut down, and under the best of circumstances takes about 10 days for a partial rebuild, longer for a complete rebuild. A rebuild involves cooldown (up to 5 days) and teardown and repairs (3 days for a partial rebuild and 7-10 days or longer for a full rebuild, depending on the extent of repairs necessary). Some gasification facilities maintain a second gasifier for use while repairs are being made, reducing system downtime and increasing on-line service and availability of the gasification system. Even then, the time to switch gasifiers can vary from hours to days, depending on if the spare gasifier is available in pre-heat mode. Because of the long down times required for repair, gasifier operators would like to install refractory linings with a reliable life of at least three years. The current generation refractory liners installed in gasifier systems have yet to meet this requirement, failing in as little as three months in high wear areas. Refractory service life is highly dependent on variables such as the carbon feedstock, the temperature of operation, material throughput, and the frequency and quality of

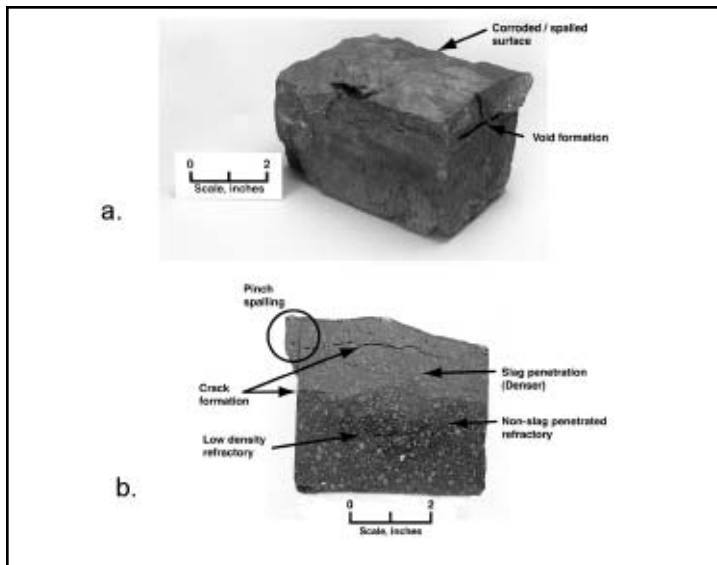


Figure 3. High chrome oxide refractory removed from a slagging gasifier; (a) hot face and (b) cross section of refractory.

plant maintenance. Differences in these variables at gasifier sites may indicate that the development or customization of high chrome refractories for each plant site may be necessary in order to achieve optimum refractory performance. Nonetheless, reliable refractory liners are needed to ensure that gasification fulfills its potential as a clean and efficient means of generating power.

POSTMORTEM ANALYSIS

High chrome oxide refractory materials at the hot face of a slagging gasifier after shutdown is shown in Figure 2. Note that the slag (and possibly feedstock and/or gas velocity) has created an irregular worn surface on the refractory liner. Refractory materials used to line a gasifier are typically dense firebrick composed of chromium oxide as the primary component, along with smaller quantities of other refractory oxides (typically aluminum and/or zirconium oxide). The wear of refractory from the hot face is thought to be caused by two principle mechanisms, corrosion and spalling. Corrosion can occur from dissolution of refractory material into the flowing slag or by dissolution of the bond phase at the hot face, followed by freeing of refractory grains into the flowing slag. This type of wear occurs continuously throughout the gasifier's service life and is gradual and predictable in a high chrome oxide refractory liner. Spalling occurs in stages, and is the irregular removal of large chunks of the refractory materials hot face into the flowing slag. Physical evidence of corrosion and spalling are both indicated in Figure 2. Note the washed-out appearance of the refractory surface (corrosion) and the spalled refractory fragment (circled in Figure 2) sliding down the gasifier sidewall.

A high chrome refractory brick removed from the hot face of a gasifier sidewall and the cross section of it are shown in Figure 3. The surface of the hot face (shown in Figure 3a) is in the latter stages of spalling, which would lead to the rapid and physical removal of a large portion of the refractory's surface, leading to a shorter refractory service life. Bakker [16] indicated spalling as a refractory wear mechanism, and demonstrated how the repeated occurrence of it during a gasifier's

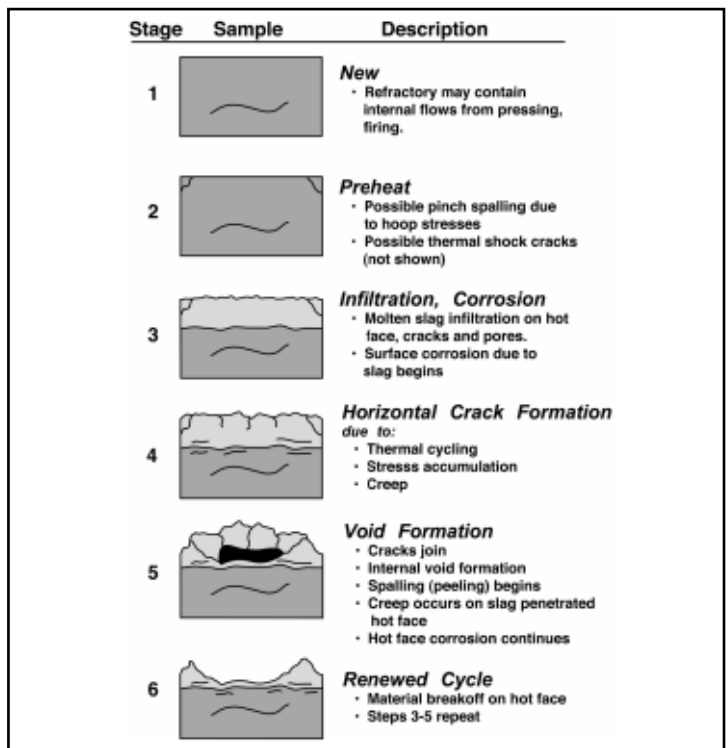


Figure 4. Stages of refractory wear.

operation would lead to an incremental and rapid shortening of refractory service life versus the predictable and gradual linear wear caused by corrosion.

Spalling and crack growth at different areas associated with slag penetration into a refractory are shown in Figure 3b. Cracks form and link together in the slag penetrated or slag penetrated/non-penetrated interface of the refractory, creating a situation where large surface portions of a refractory may become freed from the base refractory (spalled). Creep, corrosion, thermal cycling of the gasifier, an oxidizing/reducing atmosphere, or new mineral phase formation brought about by slag interactions with the refractory may all contribute to spalling. The creation, growth, and joining of cracks appears to be a reoccurring process during the operation of a gasifier. Spalling has occurred in many refractory applications and has many causes [17].

The stages of a gasifier refractory wear at different times and how these stages lead to refractory failure by corrosion and spalling is shown in Figure 4. The first stage of the process indicates when a refractory lining has been installed, and shows internal laminations or low-density areas associated with the material's manufacture. Flaws such as these may exist in the refractory because of manufacturing practices, but they can be eliminated or minimized through inspection of the refractory material before installation. Stage 2 indicates hoop stress cracking occurring at the refractory hot face edge (a rare phenomenon) and the possible formation of thermal shock cracks (not shown because this type of flaw is location specific). Once a gasifier is in service and slag has contacted the brick's hot face, it causes surface corrosion and begins to penetrate the pores of the refractory, as shown in stage 3.

The molten slag attack leading to corrosion and spalling of a chrome oxide refractory hot face starting in stage 3 and build-

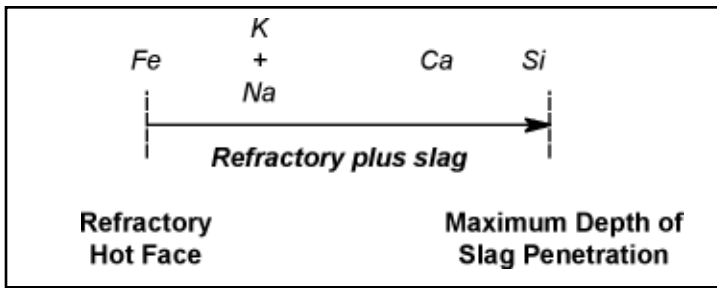


Figure 5. Relative penetration of slag elements into the microstructure of a high chrome oxide refractory.

ing up to spalling shown in stage 5 occurs throughout a gasifier operation. Corrosion is limited to the interaction between slag components and the refractory, and is influenced by gasifier operational temperature and the melting point, solubility, and fluidity of new phases that are formed. Chrome oxide works well preventing corrosion because it interacts with the slag to form high melting phases in situ. In doing so, it also raises the silica content (and thus viscosity) of the slag that has penetrated the refractory, limiting further slag penetration. It should be noted that particulate wear (abrasion) from carbon feedstock caused by burner alignment or feedstock throughput may appear to be corrosive wear on the refractory surface rather than abrasion. Wear of this type can be difficult to ascertain.

Spalling (stages 3-5 in Figure 4) may be initiated by many causes. Slag penetration and interactions between the slag and the refractory form new phases with different thermal expansion that could lead to crack formation and stresses. Once slag has penetrated a refractory surface, density/expansion differences between the penetrated/non-penetrated refractory also exist that could lead to crack formation and spalling. Spalling may also be influenced by iron compounds that interact in the slag/refractory, forming spinel or solid solution phases with an

expansion behavior different in the refractory or that may change with the oxidizing/reducing state of the gasifier. Other operational practices, like depressurization of the gasifier while the hot face is at or near operating temperature, rapid or uncontrolled gasifier shutdown, oxidizing preheats/shutdowns of the gasifier, gasification vessel design/construction, refractory creep, or thermal cycling of the gasifier could be additional causes or contributing factors to hot face spalling. Figure 4 does not discuss these causes of refractory failure, only indicating the stages of failure.

Previous work on samples penetrated by slag [18] have shown that iron penetration from slag into a refractory generally did not occur to any appreciable depth, being limited to the surface, while calcium, aluminum, and silica penetrate much deeper into the refractory structure. The relative depth of slag element penetration into a high chrome oxide/alumina refractory is shown in Figure 5. Most elements in the slag react with the $\text{Cr}_2\text{O}_3/\text{Al}_2\text{O}_3$ refractory matrix to form glass, solid solutions, or spinels, or other new phases. Based on microstructural analysis, the role of aluminum in the refractory matrix is unclear since it is already present in high chrome oxide refractories. Evidence suggests alumina may be removed from matrix aggregate into the slag in certain situations, although additional research is needed to clarify its behavior. Calcium oxides react with silica to form calcium silicates, tending to form fluid, low melting slag compositions that penetrate deep into the refractory. The high silica slag that penetrates furthest into the hot face of the refractory is thought to increase in viscosity as other oxide components of the slag interact with the refractory matrix, causing the slag to become so viscous that further penetration effectively stops. The thermal gradient, ΔT , across the hot face refractory is small, making it unlikely that it alone is the cause of the slag "freezing."

Although spalling and corrosion are thought to be the primary causes of refractory failure, evidence that other mechanisms of

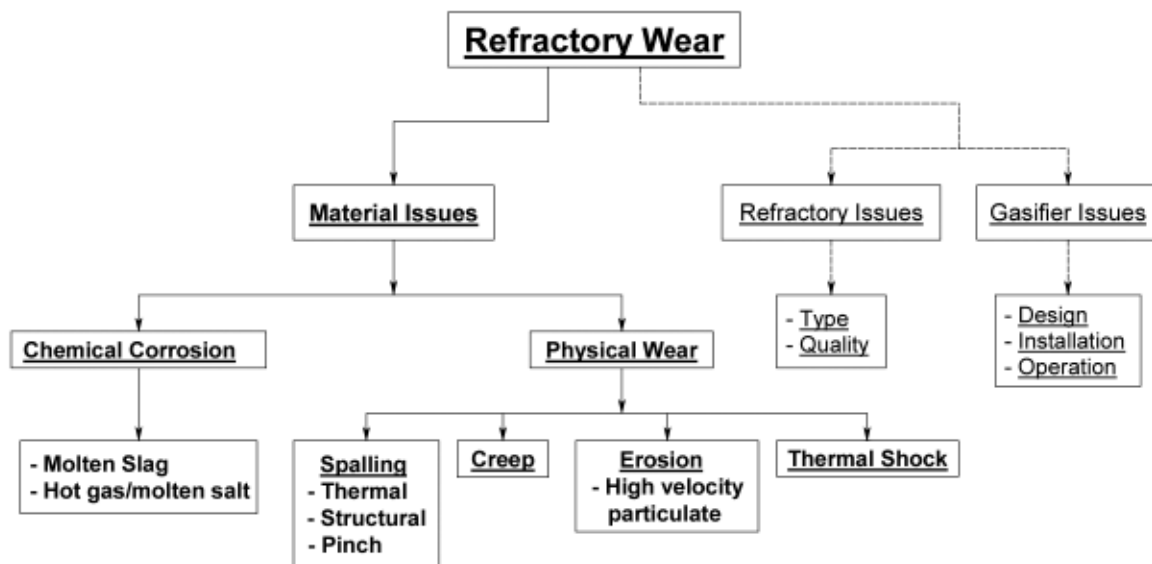


Figure 6. Causes of refractory wear in a slagging gasifier.

refractory wear such as hot gas corrosion or salt buildup in the refractory have been noted and may occur in specific gasifier locations.

A flowsheet breaking down the major types of refractory wear in a slagging gasifier is shown in Figure 6, with the causes categorized as material, refractory and gasifier issues. Gasifier and refractory issues are indicated by a dashed line in Figure 6 as they tend to remain fixed gasifier issues over a period of time, being determined by economic and production issues. Material issues that lead to gasifier wear during its operation are impacted by chemical corrosion and/or physical wear. It is important to make a study of all possible causes of wear in a gasifier to determine how they can be impacted by system changes. All causes of refractory wear tend to be lumped together into a single category of refractory failure, complicating corrective action.

TRENDS IN REFRACTORY MATERIAL DEVELOPMENT

The major types of high chrome oxide refractories used in an entrained-flow air cooled slagging gasifiers are indicated in Table 1. Differences exist in the performance of the different types of refractories, with the chrome-alumina and chrome-alumina-zirconia based compositions (A and B) now predominately used in industry. High chrome oxide content refractories (greater than 85 wt.% Cr₂O₃) are used in the severe wear areas of a gasifiers, with lower chrome oxide content materials used to line less severe wear areas of the gasifier, resulting in a zoned lining. This is done in part because of high material cost of the high chrome oxide materials. Variations in some refractory compositions are made to give special properties to a material, such as thermal shock resistance. Changes such as these have resulted in many different linings being used in gasifiers as users seek the longest lasting materials at the best price. Gao [14] has indicated one lining makeup, for instance, as a high chrome oxide material on the hot face, followed by an 85 wt.% Al₂O₃/13 wt.% Cr₂O₃ backup lining, although up to six layers of refractory insulation have been reported [1]. Regardless of the refractory lining or its makeup in a gasifier, worn linings or voids in a lining can result in dangerous hot spots on the gasifier containment shell, a situation which must be prevented.

Research is on-going to develop new or improved refractory liner materials for use in slagging gasifiers, especially in high chrome oxide compositions. The Albany Research Center, for instance, has developed and is testing the performance of a high chrome oxide refractory material with phosphate additions

Table 1. High chrome oxide refractory material composition (approximate) used in air cooled entrained-flow slagging gasifiers

Element	Composition (wt. %)		
	A	B	C
Cr ₂ O ₃	90	87	80
Al ₂ O ₃	10	3	
ZrO ₂		7	
MgO			20

[19]. Other future research trends could be towards developing refractory materials coatings, monolithic linings, or refractory materials that do not contain chrome oxide or are low in chrome oxide. Research is underway at the Albany Research Center into non-chrome oxide refractories for the following reasons: 1) the high cost of chrome oxide refractories, 2) the potential for the formation of hexavalent chrome during service (not currently known to be an area of concern), 3) the difficulty in fabricating and sintering high chrome oxide materials, 4) handling difficulties of high chrome oxide refractories due to their density, 5) possible supply issues associated with high chrome oxide refractories and 6) the fact that high Cr₂O₃ refractories have not met the performance requirements of gasifiers. Greater recycling of spent linings from gasifiers could also be encouraged. Recycling is limited because of frequency of generation issues, shipping costs and distances, storage costs, and mixed lining issues.

CONCLUSIONS

Air cooled entrained-flow slagging gasifiers are lined with high chrome oxide refractory material. The gasifier acts as a containment vessel to react carbon feedstock (typically from coal or petroleum coke) with water and oxygen in a reducing environment to produce CO and H₂, along with lower levels of other gases. Gasifiers are used for power generation or to produce chemicals for other processes. Slagging gasifiers have service lives ranging from three months to two and one-half years, with longer service life desired. The service life of a gasifier refractory is dependent upon feedstock, the temperature of operation, material throughput, and the frequency and quality of plant maintenance. Failure is typically by chemical corrosion or spalling. Improvements are being sought in refractory performance by developing new or improved refractory materials. These improvements are being sought through product reformulation, through phosphate additions to the refractory, or through the development of low or no chrome oxide refractory materials.

REFERENCES

1. W.A. Taber, "Refractories for Gasification," *Refractories Applications and News*, **8**[4] 18-22 (2003).
2. S.J. Clayton, G.J. Stiegel, and J.G. Wimer, "Gasification Technologies, Gasification Markets and Technologies – Present and Future, an Industry Perspective," U.S.D.O.E. Report DOE/FE-0447, July, 2002, 51pp.
3. W.T. Bakker, Greenberg, M. Trondt, and U. Gerhardus, "Refractory Practice in Slagging Gasifiers," *Am. Ceram. Soc. Bull.*, **63**[7] 870-876 (1984).
4. J.A. Bonar, C.R. Kennedy, and R.B. Swaroop, "Coal-Ash Slag Attack and Corrosion of Refractories," *Am. Ceram. Soc. Bull.*, **59**[4] 473-478 (1980).
5. G. Sorell, M.J. Humphries, E. Bullock, and M. Van de Voorde, "Material Technology Constraints and Needs in Fossil Fuel Conversion and Upgrading Processes," *Int. Metals Reviews*, **31**[5] 216-242 (1986).

6. S. Greenberg, and R.B. Poeppel, "The Corrosion of Ceramic Refractories Exposed to a Synthetic Coal Slag by Means of the Rotating-Drum Technique," Research Report ANL/FE--85-9, research sponsored by USDOE/FE, 15pp.
7. S. Greenberg and R.B. Poeppel, "The Corrosion of Ceramic Refractories Exposed to Synthetic Coal Slags by Means of the Rotation-Cylinder Technique: Final Report," Research Report ANL/FE—85-15, research sponsored by USDOE/FE and EPRI, April 1986, 66 pp.
8. C.R. Kennedy and R.B. Poppel, "Corrosion Resistance of Refractories Exposed to Molten Acidic Coal-Ash Slags," *Interceram*, **27**[3] 221-26 (1978).
9. C. R. Kennedy, et al., "Evaluation of Ceramic Refractories for Slagging Gasifiers: Summary of Progress to Date," research sponsored by USDOE, ANL report 78-61, Sept., 1978, 56 pp.
10. A.P. Starzacher, "Picrochromite Brick - A Qualified Material for Texaco Slagging Gasifiers," *Radex-Rundschau*, [1].491-501 (1988).
11. N.S. Raymon and L.Y. Sadler, "Refractory Lining Materials for Coal Gaisifers – A Literature Review of Reactions Involving High-Temperature Gas and Alkali Metal Vapors," *U.S. Bureau of Mines IC 8721*, 1976, 22 pp.
12. L.Y. Sadler and E.G. Davis, "Steam-Induced Volatilization of Silica from Refractories," *U.S. Bureau of Mines RI 9052*, 1986, 10 pp.
13. R.E. Dial, "Refractories for Coal Gasification and Liquefaction," *Am. Ceram. Soc. Bull.*, **54**[7] 640-43 (1975).
14. Z. Guo, "Refractories for Gasifiers," Internet Publication of the *Am. Ceram. Soc. Bull.*, www.ceramicbulletin.org, **83**[6] 9101-9108 (2004).
15. M.S. Crowley, "Refractory Problems in Coal Gasification Reactors," *Am. Ceram. Soc. Bull.*, **54**[12] 1072-74 (1975).
16. W.T. Bakker, "Refractories for Present and Future Electric Power Plants," *Key Engineering Materials*, Trans Tech Publications, (1993), Vol. 88, 41-70.
17. S.C. Carniglia and G.L. Barna, *Handbook of Industrial Refractories Technology*, pp. 226-230 Noyes Publications 1992.
18. C.P. Dogan, et al., Proceedings of Unified International Technical Conference on Refractories (UNITECR 2001), Hosted by ALAFAR, Cancun, Mexico, Nov. 4-7, 2001, Vol. 1, pp 270-275.
19. C.P. Dogan, K.S. Kwong, J.P. Bennett, R.E. Chinn, and R. Krabbe, "A New Refractory for Slagging Coal Gasifiers," *Proceeding of the 28th International Conference on Coal Utilization and Fuel Systems*, 9-14 March, 2003, Clearwater, FL. **RAM**

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Group and the Institute's Regulatory Committee will be missed, but we welcome Greg to the refractories community. Greg can be reached at: Tel: 412-294-1023, Fax: 412-293-1123, and E-mail: Greg.McDonough@rescoproducts.com.

ALMATIS TO UPGRADE PLANT

Almatis has announced a major investment in a fully integrated tabular alumina facility at their existing Qingdao plant in the Shangdong province of China. The \$18 million investment will expand existing tabular capability, supporting the installation of two shaft kilns for tabular alumina sintering and more than doubling the existing crushing and screening capacity. Under the terms of Almatis' long-term supply agreement with Alcoa, the Qingdao plant will be supplied with calcined alumina feedstock from Alcoa, Australia.

"China is the fastest growing high alumina refractory raw materials market in the world and Almatis' China sales are growing as rapidly. Our independent ownership allows Almatis to invest now, providing the Chinese refractory market continued full supply of the high quality, high alumina raw materials they need to support the shift to modern steel manufacturing and steel capacity expansion. High quality steel production demands high quality and high performance raw materials, such as Almatis' tabular alumina", stated Gangolf Kriechbaum, Almatis Chief Commercial Officer.

In addition to tabular alumina, the brownfield expansion will produce spinel and bonite, other high-grade raw materials used as aggregates in shaped and unshaped high performance refractories.

Almatis was formerly known as Alcoa World Chemicals and now operates as an independent alumina materials company, headquartered in Frankfurt, Germany.

TRI SAFETY AWARDS

TRI Chairman John Turner announced the winners of the 2004 TRI Chairman's Safety Awards at the TRI Spring Meeting. Winner in the small company category was The Nock and Son Company. The mid-size category award went to Riverside Refractories, and the large company recognition went to Unifrax Corporation.

Rob Crolius also read the list of the winners of the TRI President's Awards which were presented to facilities that operated in 2003 without a lost work time accident. They are: Inland Refractories' Avon, OH plant; Minteq International's Bryan, OH, Baton Rouge, LA, Dover, DE, and Slippery Rock, PA plants; New Castle Refractories' Newell, WV plant; The Nock and Son Oak Hill, OH plant; Refco Incorporated's Wellstone, OH plant; Refratarios Peruanos' Callao Plant; Resco Products' Cedar Heights Clay, Oak Hill, OH plant; Riverside Refractories' Pell City, AL and Nanticoke, Ontario plants; the RPC Division of Thermal Ceramics in Elgin, IL; and, the Amherst, NY and Sanborn, NY plants of Unifrax Corporation.

REGULATORY

OSHA Agenda: Silica and Hex Chrome

In the Regulatory Agenda published June 28, 2004, the Occupational Safety and Health Administration affirmed its intent to publish a final rule on hexavalent chromium by October 4, 2004. That date had been ordered by the Third Circuit Court of Appeals.

Regarding crystalline silica, OSHA indicated that a peer review of the risk assessment will be completed by February 2005. It is unclear how the agency will proceed after that. It may move expeditiously on a comprehensive regulation, or focus on some specific issues like modernizing PELs or standardizing sampling methods. **RAM**

INTERACTION OF REFRACTORIES AND ALKALINE CONTAINING CORRODANTS

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ABSTRACT

An extensive literature review has been completed and thermodynamic modeling has been employed to analyze the reactions between black liquor (BL) and aluminosilicates to understand the corrosion mechanisms of candidate refractories for black liquor gasification (BLG). Interactions of different refractory materials exposed to alkali-containing atmospheres are reviewed. Black liquor is a water solution of the non-cellulose portion of the wood (mainly lignin) and the spent pulping chemicals (Na_2CO_3 , K_2CO_3 , and Na_2S). FactSage thermodynamic modeling software was used to analyze the phases present in BL and to predict the interaction of BL with refractory compounds from the Al-Si-O system. The modeling included prediction of the phases formed under the operating conditions of a high temperature BLG process. Development of new refractory materials for BLG application is a critical issue for implementation of this technology. At the operating temperature of the BLG, FactSage predicted that the water would evaporate from the BL and that the organic portion of BL would combust, leaving a black liquor smelt composed of sodium carbonate (70-75%), sodium sulfide (20-25%), and potassium carbonate (2-5%). Exposure of aluminosilicates to this smelt leads to significant corrosion due to formation of expansive phases and, subsequently, cracking and spalling. Literature reports suggest that AZS refractories will be superior to silicates, zircon, and aluminosilicates for resistance to reaction from the alkali compounds, but these materials all undergo deleterious reactions. Other refractory ceramics such as fused spinel (altered only on the surface) and silicon nitride (dissolved in black liquor smelt) were also considered. Based on thermodynamic calculations, it appears that magnesia refractories will be stable in contact with black liquor smelt.

INTRODUCTION

Black liquor (BL) is a by-product of the papermaking process. BL is an aqueous solution containing waste organic material which is mainly lignin as well as the spent pulping chemicals which are primarily sodium carbonate and sodium sulphate [1]. Chemical energy can be recovered from BL by burning it as a liquid fuel in boiler or gasifier and BL is expected to become an increasingly important resource for electric power generation in coming years [1,2]. Chemical energy can be recovered from BL by its combustion in either boiler or gasifier [1]. Recovery boilers have been used successfully by pulp industry for many years, but they have a number of shortcomings including high capital expense, low efficiency, and potential of explosion [1, 3-4]. Black Liquor Gasification (BLG) is recognized as a technology that can

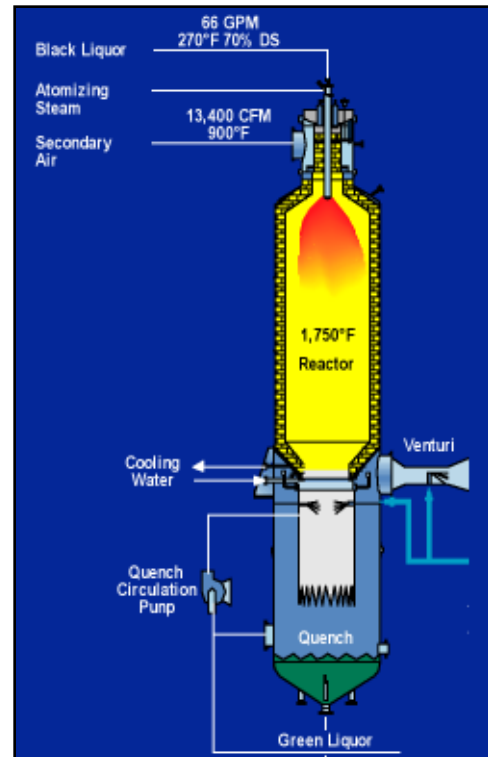


Figure 1. High Temperature Low Pressure Black Liquor Gasification Refiner [1].

replace fossil fuels to produce electricity. BLG is widely viewed as the technology that will replace the recovery boiler. Similar gasification processes are used to convert low-cost solids such as biomass or waste liquids like BL into clean-burning gases [5]. Gasification processes have the potential to partially replace fossil fuels in the production of electricity. The fundamentals of the gasification process have been reviewed before [6]. Several distinct BLG processes have been proposed, but only two of them have had satisfactory results in plant trials [7]. The first process is the low temperature process (600-700°C) developed by Manufacturing Technology Conversion International, Inc (MTCI). The other is the high temperature process (900-1000°C) developed by Chemrec [8]. The schematic configuration of a high temperature BLG reformer run under atmospheric pressure is presented in Figure 1. Both the high temperature and low temperature processes currently use air for combustion, but when oxygen is used in place of air, substantially higher gasification temperatures, up to 1400°C are possible. Higher temperatures result in higher overall process efficiencies [9].

The commercial success of BLG technology requires the development of improved refractory materials for the protective lining of the gasifier. To date, aluminosilicate based materials have been used. Both thermodynamic calculations and experience show that these aluminosilicates are not sufficiently resistant to the alkali containing atmospheres for extended operation of gasifiers. The objective of research in progress at UMR is to develop cost-effective materials with improved performance in gasifier environments.

ALKALI CORROSION OF REFRACTORY MATERIALS

Aluminosilicate refractories have been used in a variety of applications requiring contact with alkali-containing atmospheres. Interaction of aluminosilicates with alkalis has been studied widely [10-18]. Interactions of other common refractories such as zircon and alumina-zirconia-silica with alkali environments have also been studied. The remainder of this paper reviews articles that report exposure of a number of refractory materials to alkali environments and then analyzes the reported results using equilibrium thermodynamic calculations.

CORROSION ENVIRONMENTS

Wet alkali attack, which is accompanied by formation of liquid phase, produces a glassy, glazed surface on aluminosilicate refractories. The refractory is penetrated by the alkali which then reacts to form low melting compounds. At low temperatures the viscous glassy material can seal the refractory against further penetration. At higher temperatures ($\geq 1260^\circ\text{C}$) the glass is more fluid and rapidly flows off of the hot face [10, 11]. In contrast, dry alkali attack results in cracking and spalling [10]. The alkalis penetrate into the refractory and react with its components to form compounds such as nepheline, kalsilite and leucite, which have significantly larger volume than the volume of the original phases. These phases are termed as expansive phases. The presence of alkalis also causes α -alumina to recrystallize into β -alumina ($\text{Na}_2\text{O}\cdot 11\text{Al}_2\text{O}_3$ or $\text{Na}_2\text{O}\cdot 9\text{Al}_2\text{O}_3$), which is also accompanied by a large volume expansion. Thermal cycling of refractories corroded by alkali containing atmosphere causes severe disruption and cracking because of the high expansion mismatch between the refractory and reaction product. Refractory impurities also influence the rate and the extent of the alkali attack [11]. Because of physical penetration of alkalis into refractory, characteristics such as size, interconnectivity and number of pores influence the rate and depth of penetration [10, 11].

FIRECLAY AND HIGH ALUMINA REFRACTORIES

The major phases present in fireclay refractories are mullite and cristobalite. When exposed to Na_2CO_3 vapor, mullite reacted with the vapor, forming nepheline ($\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$) and α -alumina. The amount of nepheline was further increased as the Na_2CO_3 vapor reacted with newly formed alumina and the pre-existing silica. High alumina refractories are composed of corundum and mullite. When exposed to Na_2CO_3 vapor, the initial reaction product was β -alumina. At the same time, Na_2CO_3 vapor reacted with mullite to form nepheline and α -alumina. Then the sodium aluminate ($\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3$) could dissolve into nepheline to form a carnegieite solid solution ($\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$ - $\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3$ ss) [12]. A significant amount of reaction must occur

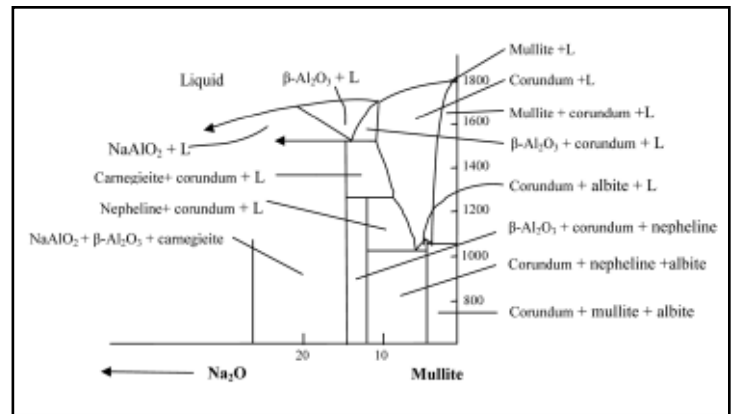
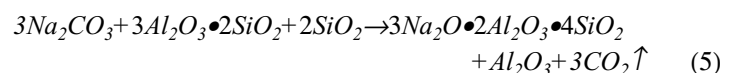
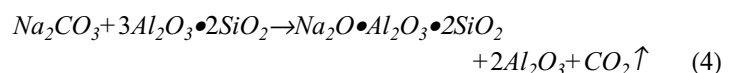
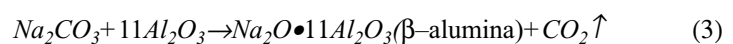
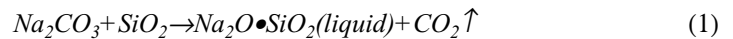


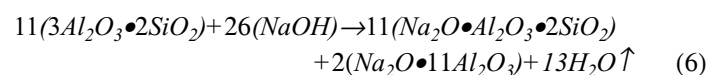
Figure 2. Na_2O -fireclay vertical section [11].

before carnegieite and sodium aluminate forms, but the formation of carnegieite actually reduces the amount of liquid phase and increases the refractoriness of the corrosion product. This result can be confirmed by Na_2O -mullite vertical section presented in Figure 2. Nepheline only forms at temperatures below 1250°C , while β -alumina forms at all temperatures. This gives β -alumina refractories a higher alkali resistance; however, β -alumina is less refractory than corundum [11].

Experiments at 1204°C showed no sign of the formation of expansive phases for a mixture of 10% Na_2CO_3 with 60% alumina brick. When the Na_2CO_3 content increases to 20%, expansive phases appeared. At 40% Na_2CO_3 , significant shrinkage associated with liquid formation was observed [10]. The proposed reactions for the interaction of sodium carbonate with mullite bonded alumina brick is as follows:



C. R. Kennedy who studied alkali attack on mullite refractories in coal gasifier, detected NaOH [13]. The formation of NaOH was thought to occur when condensed Na_2O was exposed to water vapor when the gasifier is shut down. The intermittent operation of the gasifier is probably a significant factor. The corrosion reaction is proposed as follows [13]:



It is also reported that in the range of 900 - 1400°C , the corrosion of aluminosilicate refractories by alkalis decreases as alumina content increases [11, 14]. Fused alumina shows negligible interfacial reaction. However, alumina in contact with silica tends to react when exposed to alkalis [14].

Bricks of about 60% Al_2O_3 , exposed to a potassium containing atmosphere, formed K- β -alumina ($\text{K}_2\text{O}\cdot 11\text{Al}_2\text{O}_3$ or $\text{K}_2\text{O}\cdot 9\text{Al}_2\text{O}_3$) but higher alumina and corundum refractories formed potassium aluminate ($\text{K}_2\text{O}\cdot \text{Al}_2\text{O}_3$) as well as K- β -alumina [11]. The interaction of corundum with K_2CO_3 vapor resulted in the formation of potassium aluminate and interaction of mullite with K_2CO_3 , resulted in the formation of potassium aluminate silicate solid solution ($\text{K}_2\text{O}\cdot \text{Al}_2\text{O}_3\cdot \text{SiO}_2\text{-K}_2\text{O}\cdot \text{Al}_2\text{O}_3\text{ss}$) [12, 14]. Cracking and spalling were observed in mullite bricks exposed to a potash environment as the result of formation of new compounds [14]. Yamaguchi reported that the exposure of β -alumina powder to K_2CO_3 vapor at 1200°C changed the composition from $\text{Na}_2\text{O}\cdot 11\text{Al}_2\text{O}_3$ to $(0.977\text{K}_2\text{O}\cdot 0.023\text{Na}_2\text{O})\cdot 7.5\text{Al}_2\text{O}_3$ as the result of substitution of K for Na. The lattice constant *c* of β -alumina changes from 22.54Å to 22.73Å in addition to formation of a great number of cleavages vertical to the *c* axis of the crystal [12].

Sodium sulfate condensation which results from the reaction of sodium vapor and sulfur oxides causes bloating in fireclay refractories due to formation of nepheline (<1150°C) which is enhanced in reducing conditions. Nosalite ($(3\text{Na}_2\text{O}\cdot 3\text{Al}_2\text{O}_3\cdot 6\text{SiO}_2)\cdot \text{Na}_2\text{SO}_4$), another reaction product, is a nepheline sulfate mineral and forms when nepheline reacts with sodium sulfate at temperatures above 1150°C [15].

SILICA AND HIGH SILICA REFRACTORIES

Silica refractories exposed to sodium and potassium carbonates exhibit thick corrosion product layers and depth of reaction [11, 14]. Both crystalline and glassy silica refractories are severely corroded by Na_2CO_3 and NaOH vapors at 1370°C. NaOH vapor is more aggressive than Na_2CO_3 [16]. The reaction of KOH appears to be even more aggressive than NaOH. A high degree of inter-joint reaction between silica especially in KOH atmosphere was observed [14]. Brown et al. reported that Na_2O reacted rapidly with high silica refractories, 10% Na_2O in silica refractories formed 50% liquid at temperatures as low as 1100°C [11]. But it was also reported that at 950°C, high silica (~60% SiO_2) refractories performed better than high alumina refractories because high silica refractories reacted more rapidly with the alkali to form a viscous glass sealing the pores and limiting further attack at the surface [13]. In silicate refractories containing appreciable amounts of alumina, albite ($\text{Na}_2\text{O}\cdot \text{Al}_2\text{O}_3\cdot 6\text{SiO}_2$) forms at temperatures less than 1050°C and liquid is present down to 740°C in semi-silicate refractories. For exposure to K_2O , high silica refractories formed leucite ($\text{K}_2\text{O}\cdot \text{Al}_2\text{O}_3\cdot 4\text{SiO}_2$) and kaliophilite ($\text{K}_2\text{O}\cdot \text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$) [11].

ZIRCON REFRACTORIES

When zircon (ZrSiO_4) refractories were exposed to sodium carbonate vapor, fine-grained zircons decomposed into baddeleyite (ZrO_2) and a siliceous glass. The formation of baddeleyite began at 1100°C and increased with increasing temperature up to 1400°C. Further, the continuous supply of sodium containing vapor may produce sodium zirconium silicates. The new phases were presumed to have the chemical composition of $\text{Na}_2\text{O}\cdot \text{ZrO}_2\cdot 2\text{SiO}_2$, $2\text{Na}_2\text{O}\cdot 2\text{ZrO}_2\cdot 3\text{SiO}_2$ and $\text{Na}_2\text{O}\cdot \text{ZrO}_2\cdot \text{SiO}_2$ which were formed from inner layers through the outer layers of the brick. $\text{Na}_2\text{O}\cdot \text{ZrO}_2\cdot 2\text{SiO}_2$ formed initially at 1100°C and was gradually replaced by $2\text{Na}_2\text{O}\cdot 2\text{ZrO}_2\cdot 3\text{SiO}_2$ and $\text{Na}_2\text{O}\cdot \text{ZrO}_2\cdot \text{SiO}_2$ as Na_2CO_3 vapor was supplied. Higher temperatures and prolonged time promoted $\text{Na}_2\text{O}\cdot \text{ZrO}_2\cdot \text{SiO}_2$ formation. In the case of exposure to

Na_2SO_4 vapor, baddeleyite and $\text{Na}_2\text{O}\cdot \text{ZrO}_2\cdot 2\text{SiO}_2$ were the only corrosion products. For exposure to NaCl, only decomposition of zircon into baddeleyite and a siliceous glass was observed [17]. The performance of the refractories was related to the reactivity of the vapor species; in this case with Na_2CO_3 , Na_2SO_4 and NaCl [16, 17]. Consequently, a highly reactive vapor, such as Na_2CO_3 , affects only the surface of refractory because of rapid formation of a protective glassy phase that limits further vapor penetration and reaction. Vapors with lower reactivity such as Na_2SO_4 and NaCl, are able to infiltrate further into the refractories through the pores and interstices and then react with a greater volume of the refractory [17]. The attack by molten Na_2CO_3 was much more drastic than by Na_2CO_3 vapor because of high concentration of alkalis in the melt which supplies sodium species that reacted more rapidly than the vapor [16, 17]. In the case of exposure to K_2CO_3 vapor, zircon reacted initially to form $\text{K}_2\text{O}\cdot \text{ZrO}_2\cdot 3\text{SiO}_2$ and baddeleyite which subsequently formed $\text{K}_2\text{O}\cdot \text{ZrO}_2\cdot 2\text{SiO}_2$. No compound besides $\text{K}_2\text{O}\cdot \text{ZrO}_2\cdot \text{SiO}_2$ was found in the specimens containing more than 28% K_2O [12]. Spalling due to either volume expansion of new phases during reaction or stresses imposed to the structure because of difference in the thermal expansion coefficient between the altered zone and the original body was reported as the failure mechanism. At high temperatures formation of glassy phase led to the failure [17].

AZS REFRACTORIES

$\text{Al}_2\text{O}_3\text{-ZrO}_2\text{-SiO}_2$ (AZS) refractories are composed of corundum and baddeleyite primarily and silica was present as an aluminosilicate glassy phase with the approximate composition of albite [12, 16]. These refractories showed substantial improvement over zircon and aluminosilicates with respect to the degree of reaction with alkali vapors. However AZS refractories were still vulnerable to spalling. A decrease in alumina content and lower apparent porosity tended to improve resistance to potash vapor [14]. Exposure of AZS to sodium carbonate vapor resulted in the formation of nepheline and carnegieite solid solution due to interaction of alumina and the glassy phase with sodium carbonate. Sodium zirconate ($\text{Na}_2\text{O}\cdot \text{ZrO}_2$) was the other reaction product, which formed by reaction of baddeleyite with sodium carbonate. In the case of exposure to K_2CO_3 vapor, kalsilite ($\text{K}_2\text{O}\cdot \text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$) and then a potassium aluminosilicate solid solution were formed as the result of interaction of alumina and the glassy phase with K_2CO_3 vapor. A K_2O -rich glass was also formed as the result of interaction of baddeleyite with K_2CO_3 vapor. The conversion of the potassium aluminate silicate solid solution to a K_2O rich glass is reported as well [12].

Barrie et al. suspended AZS refractory samples over molten Na_2CO_3 at 1371°C for 24 hours. If water vapor was present, formation of NaOH was probable. At higher temperatures up to 1470°C, the chemical species were not only liquid Na_2CO_3 but also some liquid NaOH and gaseous CO_2 , H_2O and Na_2O . Different zones appeared in the samples exposed to alkali vapors at 1371°C. The gray central core graded into a more bleached zone, then into a zone which was slightly yellow composed of smaller crystals of baddeleyite with a weaker pattern of $\alpha\text{-Al}_2\text{O}_3$. In this yellow band, the original dendritic texture of baddeleyite was broken up into smaller aggregates of ZrO_2 mass crystallites. The outermost layer, mottled white and light gray, was porous and had a "warty" outer surface. This zone appeared to be composed of porous aggregates

Table I. Typical composition of black liquor from North American woods (wt %) [19]

	Softwood		Hardwood	
	Typical	Range	Typical	Range
Carbon, %	35.0	32-37.5	34.0	31-36.5
Hydrogen, %	3.5	3.4-4.3	3.4	2.9-3.8
Nitrogen, %	0.1	0.06-0.12	0.2	0.14-0.2
Oxygen, %	35.4	32-38	35.0	33-39
Sodium, %	19.4	17.3-22.4	20.0	18-23
Potassium, %	1.6	0.3-3.7	2.0	1-4.7
Sulfur, %	4.2	2.9-5.2	4.3	3.2-5.2
Chlorine, %	0.6	0.1-3.3	0.6	0.1-3.3
Inert, %	0.2	0.1-2.0	0.5	0.1-2.0
Total, %	100.0		100.0	

Table II. Composition of the residual solids after dehydration of BL (wt %)

Constituents	Na ₂ CO ₃	Na ₂ S	K ₂ CO ₃	C
%	50-55	25-30	1-3	15-20

Table III. Smelt composition in contact with Refractories and the melting point of each component (wt%)

Constituents	Na ₂ CO ₃	Na ₂ S	K ₂ CO ₃
%	70-75	20-25	2-5
Melting Point (°C)	858	1172	901

of poorly crystalline of mixed hydrated carbonates and hydroxides of sodium. Sodium aluminate may have been present in minor amounts [16].

OTHER REFRACTORIES

Peascoe et al. reported the behavior of mullite, magnesium aluminate spinel, magnesia, alumina, alumina-chromia and silicon nitride refractories exposed to black liquor smelt at 1000°C. Molten smelt attacked mullite and formed sodium aluminosilicates accompanied by a dramatic volume expansion (~30%). Spinel refractories with polycrystalline spinel in a magnesia matrix showed minimal penetration and reaction due to minimal porosity and lack of reactive phases such as corundum in the matrix. Fused spinel containing large spinel crystals was altered only near the surface due to low porosity. Samples containing corundum or components such as CaAl₄O₇ in the matrix were not resistant to black liquor smelt. β-silicon nitride sample dissolved in the molten smelt [18]. Minimal reaction was observed in magnesia based refractories [10, 18]. Despite its chemical stability to black liquor smelt, there were some concerns with magnesia refractories including high thermal expansion, high thermal conductivity and the potential for hydration [10]. The soda reaction with forsterite (2MgO•SiO₂), the bonding phase in magnesia and magnesia-chrome refractories, formed a complex of Na₂O•MgO•SiO₂ phase and free soda [10]. Formation of 2Na₂O•MgO•3SiO₂ was reported as well [12]. Reaction of soda with dicalcium silicate (2CaO•SiO₂), the bonding phase in magnesia refractories, resulted in the formation of Ca₂O•Na₂O•SiO₂ complex phase and free lime [10]. Sections of the specimen after immersion corrosion test showed molten smelt penetrated the pores and attacked the interior of the chromia/alumina sample with the primary reaction products being sodium aluminate and sodium chromate (Na₂O•Cr₂O₃) [10, 18]. Spinel forms sodium aluminate when it was penetrated by BL smelt. The principal products of reaction of forsterite and

spinel with K₂O were potassium magnesium silicate (K₂O•MgO•SiO₂) and potassium aluminate respectively [12].

THERMODYNAMICS OF INTERACTION OF ALUMINOSILICATE REFRACTORIES WITH BLACK LIQUOR SMELT

FactSage 5.1 is a thermodynamic modeling package that contains a database of thermodynamic properties and performs thermodynamic equilibrium calculation based on Gibbs free energy minimization. As with all thermodynamic models, FactSage predicts equilibrium and does not take into account kinetic or microstructural factors. Experiments are necessary to verify the predictions.

The typical composition of black liquor introduced into the BLG reformer is presented in Table I [19]. The reported composition was in the form of elemental analysis, but FactSage can convert this into an equilibrium compound composition (Table II). The phase/compound composition was modeled at 950°C at a pressure of 1atm.

After the free carbon in black liquor is combusted, the composition of the resulting smelt that would then contact the refractory lining is 70-75% Na₂CO₃, 20-25% Na₂S and 2-5% K₂CO₃ (Table III). Formation of sodium sulfate (Na₂SO₄) was predicted by FactSage when the amount of oxygen introduced to the gasifier was more than the stoichiometric amount necessary to burn the organic portion of black liquor. But no data is reported about the oxygen content, in the atmosphere of existing BLG reformers.

FactSage predicted that about three quarters of the black liquor smelt was composed of sodium carbonate, which would be liquid at the operating temperature of high temperature BL gasifiers. Consequently, the selection of refractory materials for this application must be based upon resistance to molten sodium carbonate; although interactions with Na₂S and K₂CO₃ should not be ignored. Based on information of Table III, Na₂S should not be as corrosive as the two other components, because it is in solid state at the oper-

Table IV. Products of the reactions between BL smelt and aluminosilicates at 950°C

Refractory Compound \ Reaction Product	Corundum	Mullite
Corundum	-	×
β"-alumina	×	-
β-alumina	×	-
K-β"-alumina	×	-
Nepheline	-	×
Albite	-	×
Leucite	-	×

(×): the phase is formed, (-): the phase is not formed

ating temperature of the BL gasifier. In contrast, Na₂CO₃ and K₂CO₃ are present as a liquid solution that coats the inner surface of the gasifier. No evidence of solubility of Na₂S in liquid was found in available phase diagrams or predicted by FactSage. Na₂SO₄ melts at 884°C, which was below the operating temperature of BLG; therefore, sodium sulfate should be considered as a liquid part of the smelt in contact with refractory if the condition required for its formation is provided. The analysis that follows has considered only the presence of Na₂S.

FactSage predicts that the main compounds present in aluminosilicate refractories are corundum, mullite and meta-stable aluminosilicate compounds (andalusite, silimanite or kyanite). Because the aluminosilicate phases are meta-stable, at 950°C, only the stable compounds (e.g., mullite and alumina) were modeled in this analysis. If these refractory compounds were exposed to black liquor smelt at 950°C and P_{total}=1atm, the reaction products for corundum would be mainly β"-alumina (Na₂O•12Al₂O₃) (~75%) and β-alumina (10%), and for mullite would be nepheline (~50%) and corundum (~40%). The total composition is summarized in Table IV. The atmosphere of BLG gasifier formed under these conditions would be mainly composed of CO and H₂.

To summarize the information presented in Table IV, it was predicted that none of the aluminosilicate refractory compounds were resistant to either Na₂CO₃ or BL smelt at 950°C, which is the temperature of gasification in High Temperature processes. Products formed by the reaction of BL smelt with corundum have a substantially larger volume than the original refractory. For example, mullite refractory exposed to BL at 1000°C, showed about 30% volume expansion and alumina refractory, 13%. Up to 0.7% expansion is reported for α-alumina + β-alumina under the same conditions [18]. Volume expansion promotes crack formation and spallation of the refractory, which, then exposes the underlying materials allowing for further attack.

In the case of mullite, thermodynamic equilibrium calculations predicted that nepheline, albite, leucite and corundum would form. All of these phases were in the solid state under BLG operating conditions. By the same mechanism as described for corundum, large volume increases accompanied by formation of new phases such as nepheline (about 30%) would be enough to nucleate and propagate cracks in the material structure, decreasing the lining life due to spallation. The corundum, formed as the reaction product of mullite with BL would be attacked again with black liquor smelt

and corroded by the same mechanism. The vaporization of refractory constituents was negligible under these conditions.

CONCLUSIONS

At low temperatures, spalling, bloating and peeling would be the wear mechanisms of aluminosilicate refractories in contact to BL while at high temperatures, viscous flow. Based on FactSage, BL smelt converted α-alumina to β"-alumina, β-alumina and K-β-alumina, and converted mullite to nepheline, albite, leucite and corundum. All these phase transformations were accompanied by volume expansion leading to spallation. Literature reports are consistent with the results of thermodynamic calculations. Exposure of aluminosilicates to sodium-containing alkali compounds such as Na₂CO₃ resulted in the formation of nepheline and carnegieite. Exposure to potassium alkalis resulted in kalsilite and leucite formation. Corundum exposed to alkalis forms β-alumina, sodium aluminate and potassium aluminate. AZS refractories showed improvement towards alkalis over zircon and aluminosilicates but they were not entirely resistant. Magnesia was found resistant to corrosion by BL smelt and spinel in a magnesia matrix showed minimal reaction.

REFERENCES

1. J. R. Keiser, R. A. Peascoe, C. R. Hubbard, "Corrosion Issues in Black Liquor Gasifiers"; pp. 19 in *Corrosion/2003 Conference Proceedings*, NACE International, San Diego, CA, 2003.
2. L.L. Stigsson, B. Hesseborn, "Gasification of Black Liquor"; Section B, pp. 277-295 in *International Chemical Recovery System Proceedings*, Montreal Technical Section, CPPA, Toronto, Ontario, Canada, 1995.
3. C. L. Verrill, J. B. Kitto, J. A. Dickinson, "Development and Evaluation of a Low-Temperature Gasification Process for Chemical Recovery from Kraft Black Liquor"; pp. 1067-1078 in *International Chemical Recovery Conference Proceedings*, TAPPI Press, Tampa, FL, 1998.
4. E. Dahlquist, R. Jacobs, "Development of a Dry Black Liquor Gasification Process"; pp. 457-471 in *International Chemical Recovery Conference Proceedings*, TAPPI Press, Seattle, WA, 1992.
5. L. Stigsson, "Chemrec Black Liquor Gasification"; pp. 663-674 in *International Chemical Recovery Conference Proceedings*, TAPPI Press, Tampa, FL, 1998.
6. A. C. Brown, P. Smith, N. Holmblad, G. M. Christiansen, and B. Hesseborn, "Update of North America's First Commercial Black Liquor Gasification Plant"; pp. 33-49 in *Engineering and Papermakers Conference Proceedings*, TAPPI Press, Nashville, TN, 1997.
7. T. M. Grace, W. M. Timmer, "A Comparison of Alternative Black Liquor Recovery Technologies"; Section B, pp. 269-B275 in *International Recovery Conference Proceedings*, TAPPI Press, Toronto, Ontario, Canada, 1995.
8. E. D. Larson, D. R. Raymond, "Commercializing Black Liquor and Biomass Gasifier/Gas Turbine Technology," *TAPPI J.*, **80** [2], 50-57 (1997).

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9. S. Consonni, E. D. Larson, N. Berglin, "Black Liquor-Gasification/Gas Turbine Cogeneration"; pp. 1-9 in The American Society of Mechanical Engineers, Vol. 97-GT-273, ASME, 1997.
10. K. McAlister, E. Wolfe, "A Study of the Effects of Alkali Attack on Refractories Used in Incineration"; pp. 631-638 in Incineration Conference; Thermal Treatment of Radioactive, Hazardous Chemicals, Mixed and Medical Wastes Proceedings, Edited by M. E. Wacks, S.I., Albuquerque, New Mexico, 1992.
11. N. R. Brown, R. F. Hayden, J. J. Brown Jr., "Alkali Vapor Attack of Alumino-Silicate refractories," *Mat. Sci. Forum*, **34-36**, 711-715 (1988).
12. A. Yamaguchi, "Reactions between Alkaline Vapors and Refractories for Glass Tank Furnaces"; pp.1-8 in Tenth International Congress on Glass Proceedings, Edited by M. Kunigi, M. Tashiro and N. Saga, Ceramic Society of Japan, Kyoto, Japan, 1974.
13. R. C. Kennedy, "Alkali attack on mullite refractory in the grand forks energy technology center slagging gasifier," *J. Mat. for Energy Systems*, **3**[6] 27-31 (1981).
14. A. E. Thomas, "A Study of Soda and Potash Vapor Attack on Super Structure Refractories", *J. Can. Ceram. Soc.*, **44**, 37-41 (1975).
15. J. R. LeBlanc, "Brockway's Lower Checker Sulfate Test," *J. Can. Ceram. Soc.*, **52**, 58-60 (1983).
16. H. B. Barrie, "Corrosion of AZS, Zircon and Silica Refractories by Vapors of NaOH and of Na₂CO₃," *Am. Ceram. Soc. Bull.*, **61**[7] 745-749 (1982).
17. T. Fukui, H. Ogawa, "Corrosion of Zircon Refractories by Vapors of Sodium Compounds," *Ashi Gvasu Kenkyu Hokoku*, **17**[2] 77-98 (1967).
18. R. A. Peascoe, J. R. Keiser, C. R. Hubbard, M. P. Brady, "Performance of Selected Materials in Molten Alkali Salts"; pp. 189-200 in 10th International Symposium on Corrosion in the Pulp and Paper Industry Proceedings, Technical Research Centre of Finland, Helsinki, Finland, 2001.
19. J. Gullichsen, H. Paulapuro, "Chemical Pulping", pp. B13-B18, Paper Making Science and Technology series book; Published in cooperation with the Finnish Paper Engineers' Association and TAPPI Book 6B, 1999. 

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Call for nominations for The Theodore J. Plange -- St. Louis Refractories Award

In December, 1967 the St. Louis Section of the American Ceramic Society announced the establishment of an award to be known as "The St. Louis Refractories Award." This has been provided in Article XII of the by-laws of the St. Louis Section "for the purpose of recognizing and honoring distinguished achievement in the refractories field." The same article established the Award Committee to consist of the Section Counselor, the Trustee of the Refractories Division of the American Ceramic Society, and three other section members appointed annually by the Section Executive Committee.

In March, 1982 the St. Louis Section voted to amend Article XII of the by-laws. The award was renamed to "The Theodore J. Plange -- St. Louis Refractories Award" in honor of his many contributions. Nominations received after December 1, 2004 shall be held for the following year. To request a nomination form contact William L. Headrick: bill@umr.edu



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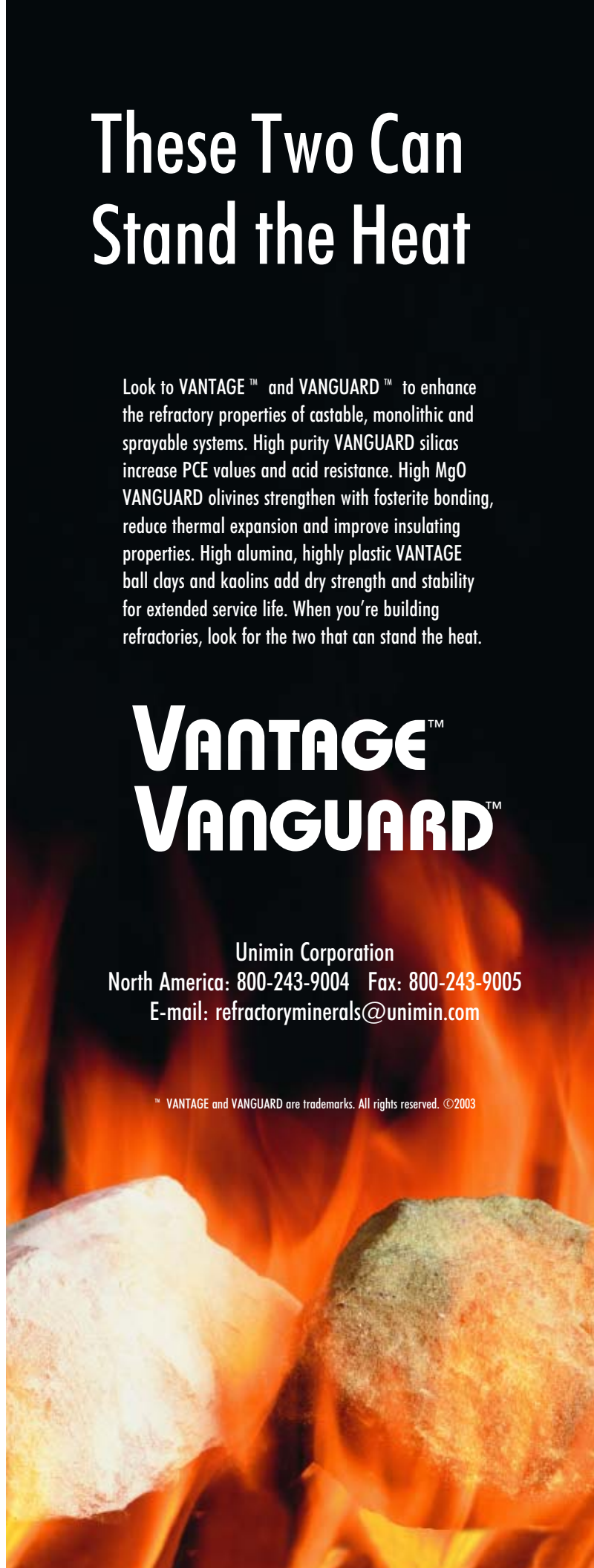
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