

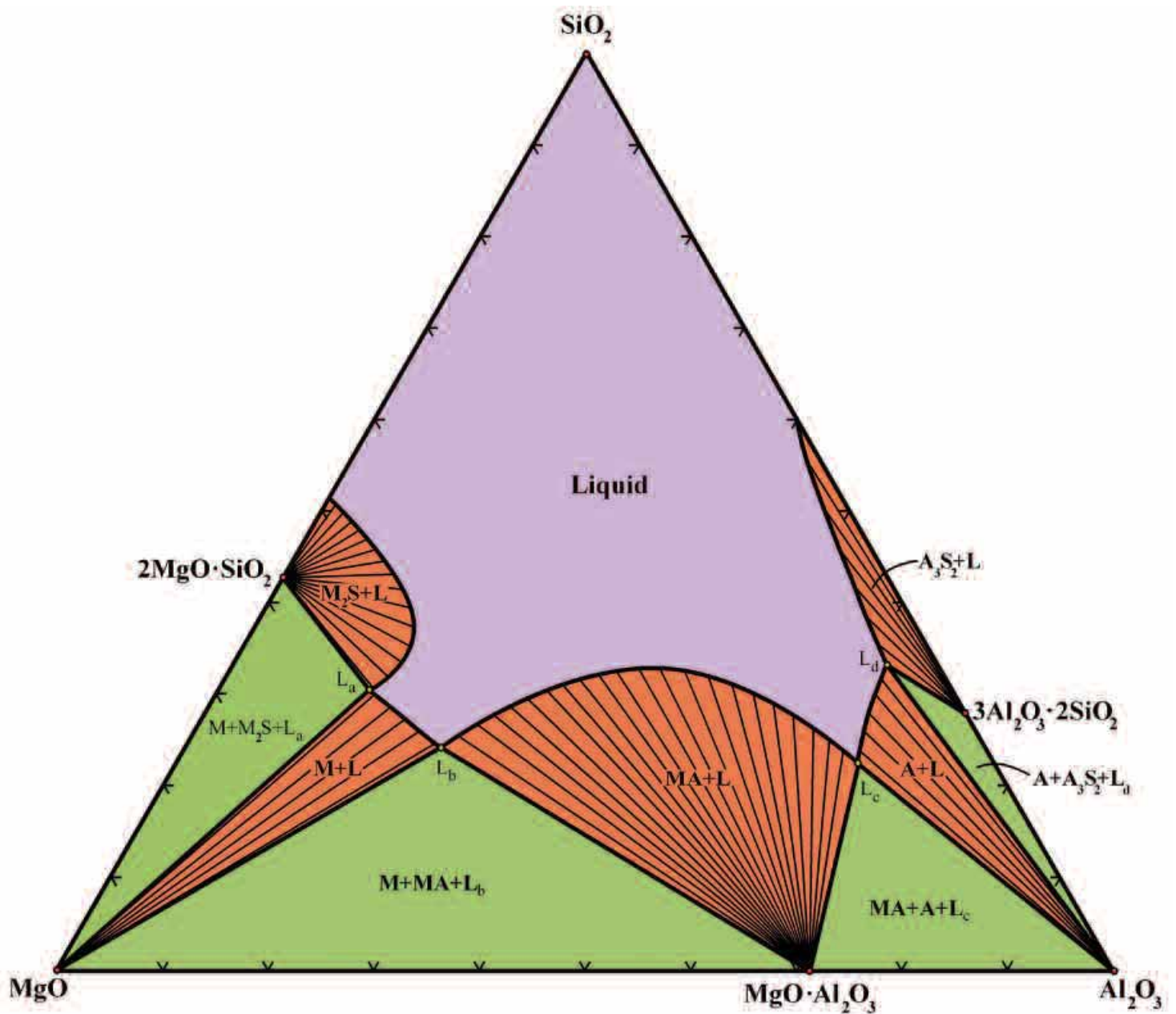
# Refractories Applications *and News*



[www.ranews.info](http://www.ranews.info)



Technology Bimonthly for the Global Refractories Industries



**MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> System  
1800°C Isothermal Section**



## THE REFRACTORIES INSTITUTE

*Is pleased to announce the availability of a new DVD  
entitled,*

### ***“Taming the Flame: The Story of Refractories”***

*Intended for a general audience, the DVD discusses the range  
of refractory products, how they are made, and the importance  
of refractories to modern manufacturing and society.  
(8.5 minutes)*



***Cost: \$20 for TRI members, \$30 for nonmembers,  
postage included.***

***Discounts available for schools and volume purchases.***

***For membership information  
contact:***

The Refractories Institute  
P.O. Box 8439  
325 Maple Avenue  
Pittsburgh, PA 15218  
Phone: (412) 244-1880 Fax: (412) 244-1881  
rob@refractoriesinstitute.org

## Time for a change?

Jeffrey D. Smith, Editor, [jsmith@mst.edu](mailto:jsmith@mst.edu)



Jeffrey D. Smith


A few issues ago I wrote an editorial that effectively asked *RAN* readers to comment on their feelings about this journal, its style, its format, and most importantly, its usefulness as a resource for them personally and for their company or institution. The request, you may recall, was predicated by my observation that advertising in *RAN* had dropped over the past year or so, in keeping with the downturn of the economy.

I am pleased to report that the response was swift and substantial. Most of the responses were extremely positive and many indicated potential avenues to consider for reducing costs during these tough times. All of these comments were appreciated, as all future comments will be as well.

I would like to add that none of the responses indicated that a particular company wanted to place an advertisement in the journal. I was not surprised and I am certain that none of you are surprised as well. I am not upset by it either, as I hope none of you are upset reading about it now. Times are difficult and likely will stay difficult for some time and none of us can hold out hope that someone will come along and fix things for us.

We are all good at what we do and it is times like these that prove it. Like you, we continue to find ways to do more with less. One approach we are considering is to offer *RAN* as an electronic-only publication. This would not reduce the effort required to produce the publication but it would significantly reduce the cost. My fear of this "solution" rests in your response to such a change. If advertising revenues decline (I expect on-line ads to be viewed less favorably) with the reduced publication costs, little is accomplished by the change in format.

My colleagues in this industry have never been shy about voicing their opinions. Therefore, I leave you as contributors, advertisers, and readers, to consider the following:

"How would *RAN* moving to an on-line-only publication impact you and your company?" 

**Front Cover** - An isothermal section constructed for a temperature of 1800°C in the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system is included. Consistent coloring scheme is used to highlight the different equilibria in the system with purple indicating a single-phase region, rust indicating a single solid in equilibrium with liquid and green indicating two solids in equilibrium with liquid. Refer to corresponding *Phase Rules* manuscript for additional details.

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# Refractories Applications and News



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Technology Bimonthly for the Global Refractories Industries

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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, leemj@mst.edu, (573)341-6561, Missouri S&T, 223 McNutt Hall, Rolla, MO 65409.

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**U.S. readers who would like to subscribe or unsubscribe to this magazine should e-mail their name and address to Mary Lee at: leemj@mst.edu**

## REFRACTORIES RELATED MEETINGS

2010

January 24-29, **34<sup>th</sup> International Conference and Exposition on Advanced Ceramics and Composites**, Hilton Daytona Beach Resort and Ocean Center, Daytona Beach, FL.

Feb. 21-24, **Materials Innovation in an Emerging Hydrogen Economy**, 2010 Hilton Cocoa Beach Oceanfront - Cocoa Beach, FL.

March 24-25, **St. Louis Section and the Refractory Ceramics Division 46<sup>th</sup> Annual Symposium**, St. Louis, MO.

May 3-6, **AISTech 2010 The Iron & Steel Technology Conference and Exposition**, David L Lawrence Convention Center, Pittsburgh, PA.

June 6-18, **12<sup>th</sup> International Ceramics Congress CIMTEC 2010**, Florence Italy, [www.cimtec-congress.org/2010/](http://www.cimtec-congress.org/2010/).

September 6-10, **The 25<sup>th</sup> International Mineral Processing Congress 2010 (IMPC)**, Brisbane Convention Ctr., Australia; IMPC 2010 Event Management – The AusIMM, Tel: +61 3 9658 6123, Fax: +61 3 9662 3662, [impc2010@ausimm.com.au](mailto:impc2010@ausimm.com.au), [www.impc210.org](http://www.impc210.org), PO Box 660, Carlton South, Victoria 3053, Australia.

October 3-6, **COM 2010-Conference of Metallurgists, 5<sup>th</sup> International Symposium on Advances in Refractories**, Vancouver, BC, Canada, George Oprea: [oprea@interchange.ubc.ca](mailto:oprea@interchange.ubc.ca), [www.metsoc.org](http://www.metsoc.org)

October 17-21, **Materials Science & Technology 2010 Conference and Exhibition - MS&T '10 combined with the ACerS 112<sup>th</sup> Annual Meeting**, George R. Brown Convention Center, Houston, TX.

Nov. 14-18, **3<sup>rd</sup> International Congress on Ceramics**, Osaka International Convention Center, Osaka, Japan.

**Send meeting announcements to Mary Lee at:  
[leemj@mst.edu](mailto:leemj@mst.edu)**

**Announcements must be received a minimum of  
four months prior to the meeting date.**



**Rob Crolius**

## **U. S. INTERNATIONAL TRADE COMMISSION TO CONTINUE CASES ON CERTAIN MAGNESIA CARBON**

The United States International Trade Commission determined there is reasonable indication that a U.S. industry is materially injured or threatened with material injury by reason of imports of certain magnesia carbon bricks from China that are allegedly subsidized and

from China and Mexico that are allegedly sold in the United States at less than fair value. As a result of the affirmative determinations, the U.S. Department of Commerce will continue to conduct its countervailing and antidumping duty investigations on imports of these products from China and Mexico, with its preliminary countervailing duty determination due on or about Oct. 22, 2009, and its preliminary antidumping duty determinations due on or about Jan. 5, 2010.

The Commission's public report Certain Magnesia Carbon Bricks from China and Mexico (Investigation Nos. 701-TA-468 and 731-TA-1166-1167 (Preliminary), USITC Publication 4100, Sept. 2009) will contain the views of the Commission and information developed during the investigations. Copies of the report are expected to be available after Oct. 12, 2009, by emailing [pubrequest@usitc.gov](mailto:pubrequest@usitc.gov), calling 202-205-2000, or writing to the Office of the Secretary, 500 E Street SW, Washington, DC 20436. Requests may be faxed to 202-205-2104.

## **UNIFRAX CORPORATION ANNOUNCES ACQUISITION**

Unifrax Corporation has announced that through a U.K. subsidiary, Unifrax Europe Holdings Limited ("UEHL"), it has acquired ALFATEC Feuerfest-Faser-Technik Gesellschaft m.b.H and sister company ALFATEC Feuerfest-Vertrieb Gesellschaft m.b.H ("Alfatec"). Terms of the transaction were not disclosed.

Alfatec is located in Unterwölbling, Austria about an hour from Vienna and is a manufacturer of vacuum formed shapes and other fabricated products made from ceramic and other fibers. The business has approximately 27 employees who will be joining the Unifrax European team. Alfatec also has an ownership position in a joint venture company in China called Alfiso that will be a part of the Unifrax acquisition. Alfiso is located in Tianjin, China. Its main business is vacuum forming of ceramic fiber shapes.

Mr. Johann Haberleiter, the former owner of Alfatec, founded the business in 1986 and has led its substantial growth. He has joined Unifrax as an employee and will help to drive the continuing growth of Unifrax' value-added shapes business.

## **REFRATORIES VIDEO NOW AVAILABLE**

On the inside front cover of this journal is a large ad announcing the availability of a new DVD produced by The Refractories Institute, entitled, "Taming the Flame: The Story of Refractories." Designed for general audiences and running a little under nine minutes, the DVD briefly describes what refractories are, how they are manufactured and used, and why they are important to modern society. What is not expressed in the ad is the appreciation we have for those who helped in the production of the video. Many sequences were filmed

at the York, PA facility of LWB Refractories. Our thanks go to CEO David Gregory and his great team at LWB for providing so much support. In addition, I would like to thank the many TRI members and nonmember companies who willingly provided footage and stills for the effort as well as the member companies technical people who commented on the script.

Copies of the DVD are available to TRI members and non-profits for \$20, including shipping. Non-members may purchase copies for \$30. International shipping is extra. Call TRI at 412-244-1880 for additional information and to place an order.

## **EPA FINALIZES THE NATION'S FIRST GREENHOUSE GAS REPORTING SYSTEM/MONITORING TO BEGIN IN 2010**

On Jan. 1, 2010, the U.S. Environmental Protection Agency will, for the first time, require large emitters of heat-trapping emissions to begin collecting greenhouse gas (GHG) data under a new reporting system. This new program will cover approximately 85 percent of the nation's GHG emissions and apply to roughly 10,000 facilities.


EPA states that the new reporting system will provide a better understanding of where GHGs are coming from and will guide development of the best possible policies and programs to reduce emissions. The data will also allow businesses to track their own emissions, compare them to similar facilities, and provide assistance in identifying cost effective ways to reduce emissions in the future. This comprehensive, nationwide emissions data will help in the fight against climate change.

Greenhouse gases, like carbon dioxide, are produced by burning fossil fuels and through industrial and biological processes. Fossil fuel and industrial GHG suppliers, motor vehicle and engine manufacturers, and facilities that emit 25,000 metric tons or more of CO<sub>2</sub> equivalent per year will be required to report GHG emissions data to EPA annually. This threshold is equivalent to about the annual GHG emissions from 4,600 passenger vehicles.

The first annual reports for the largest emitting facilities, covering calendar year 2010, will be submitted to EPA in 2011. Vehicle and engine manufacturers outside of the light-duty sector will begin phasing in GHG reporting with model year 2011. Some source categories included in the proposed rule are still under review.

More information on the new reporting system and requirements: <http://www.epa.gov/climatechange/emissions/ghgrulemaking.html>

## **OSHA NOMINATION SIGNALS TOUGHER ENFORCEMENT**

President Obama has announced the nomination of Dr. David Michaels to be Assistant Secretary for Occupational Safety and Health in the U.S. Department of Labor. Michaels currently is interim chair of the Department of Environmental and Occupational Health at the George Washington University School of Public Health. In 2008, Dr Michaels authored the book, "Doubt is their Product: How Industry's Assault on Science Threatens your Health." He served as an assistant secretary in the Energy Department in the Clinton Administration. If confirmed by the Senate, Dr. Michaels is expected to move quickly on OSHA's pending publication of a proposed comprehensive crystalline silica regulation. 

### **SWECO INTRODUCES THE DC CLASSIFIER DRY, COOL AND CLASSIFY ALL IN ONE MACHINE**

Sweco, A Business Unit of M-I L.L.C., is pleased to announce the DC Classifier™, a multi-functional unit designed to dry, cool and classify all in one machine. Developed specifically for the plastics industry, the DC Classifier is perfect for any dry application requiring one, two or all three of its intended functions ... drying, cooling or classifying.

The DC Classifier utilizes either positive or negative airflow to draw moisture and heat away from the particulates to dry and/or cool the material. The material continues through the machine to the classification stages where and oversize and fine particles can be removed.

The DC Classifier was designed with modular decks for easy removal for cleaning in-between process changes when more than one material type or color is processed in the same machine. The classifier can also be designed with casters for trouble-free mobility around the lab or production facility.

Sweco serves the chemical, food, minerals, pharmaceutical, paper and many other industries with a complete line of separation, sizing and milling equipment.

For more information, please visit [www.sweco.com](http://www.sweco.com) or e-mail [info@sweco.com](mailto:info@sweco.com).

### **MFGMATCH.NET LAUNCHES NEW MARKETPLACE TO HELP U.S. MACHINE SHOPS FIND CUSTOMERS ONLINE**

The Industrial Leaders Group announced today the launch of MFGmatch.net, a custom-manufacturing marketplace to promote job shops, foundries and other contract and custom manufacturers at <http://www.mfgmatch.net>. The company said the new site was created in response of a serious need for small and medium sized job shops with limited marketing budgets to compete with larger manufacturers with a more dominate online presence.

According to Conrad Bailey, spokesperson for MFGmatch.net, the site is designed to help primarily US-based machine shops market their services and capabilities online while enabling those in the market for custom manufacturing services to submit RFQ's (request for quotes) directly to national and international manufacturers. Bailey said the focus of the site is on machined parts, precision components and other custom products constructed in various metals, plastics, rubber, wood and other materials.

For additional information contact: Don LaBelle. Public Relations, MFGmatch.net/Div. of Industrial Leaders, [info@industrialleaders.com](mailto:info@industrialleaders.com), Tel: 508-987-1947.

### **CERAM ADDS FURTHER ASTM STANDARD TEST METHODS TO ITS TESTING SERVICES**

CERAM, a global expert in materials testing, analysis and consultancy, is extending its refractory services to the glass and petrochemical industries by introducing a new range of UKAS-accredited (ISO17025) ASTM Standard Test Methods to complement their currently Accredited ISO and CEN Standard Test Methods.

The new tests are:

ASTM C133 - 97(2008)e1 Standard Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories

ASTM C20 - 00(2005) Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water

ASTM C832 - 00(2005) Standard Test Method of Measuring Thermal Expansion and Creep of Refractories Under Load

ASTM C134 - 95(2005) Standard Test Methods for Size, Dimensional Measurements, and Bulk Density of Refractory Brick and Insulating Firebrick

ASTM C113 - 02(2008) Standard Test Method for Reheat Change of Refractory Brick

The new tests will allow refractory materials manufacturers to include more extensive test data in their product specifications, thereby enabling them to better promote new or improved products. Refractory users will also benefit as the increase in test data can only help them to more effectively select and compare refractories across world markets.

As a UKAS ISO 17025:2005 accredited testing laboratory, CERAM provides a comprehensive refractories testing service, including a wide range of physical, chemical, mineralogical and thermo mechanical tests for QA/QC, failure analysis, tendering support, product specification and structural modeling purposes. Refractory materials can be inspected and sampled onsite or in CERAM's laboratory to ensure materials are suitable for use and to avoid costly delays.

In addition to its testing services, CERAM also offers consultancy to the refractory industry, ranging from raw material evaluation, refractory design and installation guidance to failure investigations, refractories analysis and technical advice.

For more information visit [www.ceram.com/refractories](http://www.ceram.com/refractories) or Tel: +44 (0) 845 026 0902.

CERAM is a global expert in materials testing, analysis and consultancy, providing customized solutions that help clients to measurably improve performance and profitability through safer, regulatory-compliant and better-engineered products. Setting new standards in materials testing, CERAM works as an extension of customers' teams, applying its expertise and capabilities to a wide range of sectors, including construction; energy & environment; automotive & transport; aerospace & defense; consumer and retail; electronics; materials & petrochemical; healthcare; and minerals.

Headquartered in Staffordshire (UK), CERAM was founded in 1920 and employs a team of research and product development professionals who are involved in physical and chemical materials testing, research, process engineering, product design and failure analysis, [www.ceram.com](http://www.ceram.com).

For further information please contact: Mandy Rymill, CERAM Marketing Communications Manager, Tel: +44 (0)1782 764 326, Email: [mandy.rymill@ceram.com](mailto:mandy.rymill@ceram.com).

### **WORLD'S LARGEST BLAST FURNACE LAUNCHED WITH ADVANCED MAGNECO/METREL TECHNOLOGY**

Magneco/Metrel, Inc. announced today that the world's largest blast furnace has begun production following the installation of nearly 2,500 tons of its innovative Metpump refractories. The silica-bonded pumpable refractories provide lining for the new

5,500-cubic-meter working volume furnace, operated by Shougang Jing Tang United Iron and Steel, Ltd. in Caofeidan, Hebei Province, China, with a capacity of more than 5 million tons a year.

Magneco/Metrel noted that a second identical facility is currently under construction at the same location, both employing cutting-edge technology to make them the flagships of China's ironmaking facilities.

"As the world's leading developer and manufacturer of refractory, we are very honored to contribute our unique technology and expertise to these historic projects," said Charles Connors, Sr., chief executive officer of Magneco/Metrel. "Our products are highly regarded for their ability to enhance performance while reducing construction costs, time and maintenance requirements."

Designed to produce up to 14,000 tons of iron per day, the stove-cooled furnace vessel is approximately 50 meters high with an internal hearth-lining diameter of 15.5 meters, and includes 42 tuyeres and four tapholes. Under terms of the agreement, Magneco/Metrel is providing and installing various formulations of its Metpump products -- manufactured at three global plant locations -- to match the range of specifications required within the new Chinese blast furnaces.

Magneco/Metrel's unique line of proprietary, monolithic, Metpump refractory products are produced with advanced colloidal silica, Sol-Gel bonded, no-cement materials that could easily and quickly applied by spray-on pumping or pouring into place, or by pneumatic shotcreting. When used in blast furnace lining system applications, this advanced nanoparticulate technology results in significantly reduced installation time, minimal dry-out and heat-up requirements, less downtime, superior performance, lower fuel rates, improved life-time and increased production availability.

When compared to low-cement or ultra-low cement bonded castables or prefired bricks, cement-free Metpump refractories provide exceptional hot strength, superior thermal shock and creep resistance, and optimal erosion, abrasion and chemical attack resistance for increased lining life potential. The high temperature strengths exhibited by Metpump refractories are typically three to four times higher than conventional cement-bonded castables.

The superior performance of Metpump refractories is continually demonstrated not only in ironmaking processes, but also in other industries worldwide, including aluminum, copper, non-ferrous and ferrous foundries; glass; direct reduction processes; AC, DC and submerged arc furnaces; reheating and melting furnaces; cupolas and rotary kilns.

For further information on the full line of Magneco/Metrel monolithic refractory products, call 630/543-6660 or visit [www.magneco-metrel.com](http://www.magneco-metrel.com).

Magneco/Metrel, Inc. is the world's leading developer and manufacturer of refractory technology, with headquarters in Addison, Illinois, and facilities in 17 countries worldwide.

#### **SWECO ANNOUNCES SHAMROCK SYSTEMS, INC. NEW REPRESENTATIVE FOR TEXAS AND OKLAHOMA**

Sweco, a business unit of M-I L.L.C., is pleased to announce Shamrock Systems, Inc. as the new representative organization serving Southern Texas. Shamrock brings expert process and SWECO equipment knowledge to the region attributable to their current standing as Sweco's representative in Northern Texas and Oklahoma.

"We are thrilled to extend Shamrock's territory into Southern Texas" said Tom Bowen, Sweco VP of Sales & Marketing. "The experience and professionalism that they have displayed in servicing our customers in Northern Texas and Oklahoma made it an easy decision when the sales territory needed to be filled. Their knowledge of Sweco equipment will assure their new customers in Southern Texas of reliable service from a new face."

Shamrock has served the material handling market for more than 30 years with various process equipment lines. In addition to Sweco, Shamrock represents companies such as K-Tron, Premier Pneumatics, Cyclonaire, Salina Vortex, Littleford Day, Sartorius and more. Shamrock has become the complete systems providers for the entire states of Texas and Oklahoma.

Sweco is a world leader in providing particle separation and size reduction solutions. Over 60 years ago Sweco invented the Vibro-Energy® Round Separator, a device that has become the standard for both wet and dry particle separation. Since then, continuous innovation has led to an expanding product line that includes customized equipment for virtually any application. For specialized wet separations Sweco offers high speed vibrating rectangular separators and high capacity centrifuges. For dry separations, Sweco offers GyraMax™ rectangular gyratory screeners, turbo air classification systems and centrifugal sifters. Sweco also manufactures a line of Vibro-Energy Grinding Mills, and replacement parts and screens for any piece of screening equipment in use today.

Sweco serves the chemical, food, minerals, pharmaceutical, paper and many other industries. For more information, please visit [www.sweco.com](http://www.sweco.com) or e-mail

#### **US DEMAND FOR COUNTERTOPS TO REACH 760 MILLION SQUARE FEET IN 2013**

US demand for countertops is forecast to increase 2.4 percent annually to 7600 million square feet in 2013. Growth will accelerate from the pace of the 2003-2008 period, prompted by a rebound in housing construction from the depressed 2008 level. While the residential remodeling segment will post below-average advances in demand through 2013, gains will be promoted by the large stock of homes requiring countertop replacement, as well as the desire of consumers to renovate their kitchens and bathrooms by installing larger-sized countertops. These and other trends are presented in countertops, a new study from The Freedonia Group, Inc., a Cleveland-based industry research firm.

Countertops made from engineered and natural stone will experience the strongest gains through 2013. Consumers view these materials as durable, aesthetically pleasing surfaces that are highly resistant to scratches and extreme temperatures. Engineered stone will benefit from its resistance to biological contaminants and its resemblance to natural stone, while remaining impervious to moisture. Natural stone will benefit from consumer interest in the luxury and style that granite and other types of stones offer. Laminate countertops will continue to account for the largest share of countertop sales.

In 2008, the residential market accounted for three-quarter of overall countertop demand. The residential market will continue to drive countertop demand through 2013, reflecting the rebound in housing construction and continued consumer interest in installing high-value countertop. The nonresidential market is forecast to contract through 2013, as decreases in non-residential construction spending will limit overall countertops

demand. Best prospects for growth in the nonresidential countertops market will be the institutional segment, as medical and educational facilities install countertops in patient rooms, classrooms and food service areas. Countertops demand in nonbuilding applications is forecast to rise, spurred by rebounding production of recreational boats and vehicles.

Corinne Gangloff, Media Relations, Tel: +1-440-684-9960, Fax: +1-440-646-0484, pr@freedoniagroup.com

US COUNTERTOPS DEMAND (million square feet)					
Item				% Annual Growth	
	2003	2008	2013	2003-08	2008-13
Countertops Demand	631	674	760	1.3	2.4
Laminates	423	426	455	0.1	1.3
Solid Surface	86	84	91	-0.5	1.6
Natural Stone	25	45	66	12.5	8.0
Engineered Stone	13	31	49	19.0	9.6
Cast Polymers, Tile & Other	84	88	99	0.9	2.4

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### ALLENTOWN SHOTCRETE TECHNOLOGY, INC. ANNOUNCES REFRACTORY PRODUCT MANAGER



**Bob Harmon**

Allentown Shotcrete Technology, Inc. announces the addition of Bob Harmon as refractory product manager. Harmon's primary responsibilities include managing and overseeing the sales of the refractory equipment product line globally as well as training and safety.

Harmon reports directly to Allentown's president, Patrick Bridger.

"Bob's vast expertise of the refractory industry will be an enormous asset to Allentown and will help propel our equipment into the global marketplace even more," says Bridger.

"I'm looking forward to the opportunity of advancing Allentown's strategy in the world refractory equipment market," comments Harmon.

Most recently, Harmon worked 21 years for MINTEQ International Inc. (MINTEQ), a global refractory products manufacturer, as manager – shotcrete application systems. During his time at MINTEQ, Harmon had multiple roles at the company including manager of customer service, manufacturing supervisor and production manager of plants in Ohio and Pennsylvania.

Harmon will be based in Grove City, Pennsylvania. He can be reached via e-mail at: harmonb@allentownshotcrete.com or by phone at: (610) 909-9519.

### PUTZMEISTER AMERICA, INC. LAUNCHES GENUINE PARTS ONLINE WEBSHOP

Offering greater convenience for its distributors, Putzmeister America, Inc. is launching its Genuine Parts Online Webshop through its web site, www.putzmeister.com, located in the Parts & Service section.

"Our new online parts Webshop provides nationwide computerized coverage for distributors to access our inventory of over

20,000 parts totaling more than \$40 million through a quick and seamless process from home or work," says Ian Moore, vice president – customer support for Putzmeister America. "The great thing about ordering your parts online is that there's no waiting on someone, waiting in line, or the need to get your order placed by 5 p.m.; all orders can be placed at your leisure at any time, 24/7. Of course, our personalized customer service is always accessible through our toll free phone line and round-the-clock fax as well."

Putzmeister offers longer lasting, better performing parts under increased wear conditions which means greater savings and less downtime. An advanced storage system at the Wisconsin headquarters makes retrieval quick and a spare parts stock order program includes recommended lists for all Putzmeister product lines.

The Genuine Parts Online Webshop features a secure online transaction process with your Putzmeister Advantage Plus card as well as your Visa, MasterCard or Amex card.

For questions, please contact Putzmeister America Customer Support toll-free at (800) 890-0269.

### ADDIDRIVE SYSTEM DEBUTS ON PUTZMEISTER AMERICA, INC.'S 70Z

The Addidrive system, the first of its kind in North America, is an innovative front drive system that provides over 12,000 pounds (5,443kg) of traction force to a unit's tractor steer axles giving it an incredible 10x10 drive configuration. The system is featured on Putzmeister America, Inc.'s 70Z-Meter truck-mounted concrete boom pump.

"With the ability to be activated on the fly, this feature is especially helpful when the unit loses traction while driving up hills or through difficult terrain," says Dave Wright, Putzmeister America's manager of engineering. "The system allows you to drive off road on job sites with added assurance that you won't get stuck in the mud."

Addidrive was a collaboration between Monroe Trucks, Poclain Hydraulics and Putzmeister America.

"In addition, fuel consumption is lower because the inefficiencies of a mechanical system are removed," Wright explains. "Because Addidrive can be activated on the fly, there is very little power consumption when it's not activated."

"The system doesn't use mechanically driven axles, drive lines or a transfer case, so it weighs about 900 pounds (408kg) less than a traditional front drive."

The system also maintains the turn radius of a unit, provides optimal vehicle control and does not require a spacer frame, so the cab height is unchanged.

"We plan to expand Addidrive as an optional feature to the rest of our product line in the future," notes Wright.

For more information on Addidrive, please contact Putzmeister America toll-free at (800) 884-7210, or visit our website at www.putzmeister.com

### EXCLUSIVE ERGONIC® SYSTEM FEATURED ON PUTZMEISTER BOOM PUMPS

Initially debuted as a standard on the 63Z-Meter pump in early 2005, Putzmeister America, Inc. is pleased to announce that its full Ergonic® system is now standard on its truck-mounted concrete

boom pump models 52Z-Meter and larger. The Ergonic Pump System (EPS) module is standard on models 31Z- through 47Z-Meter.

“The addition of the Ergonic system to these models is exciting for our customers,” says Putzmeister America vice president of sales and marketing, Bill Dwyer. “They will experience increased reliability and concrete placement performance as well as reduced equipment wear and enhanced jobsite efficiency.”

Putzmeister Ergonic technology is a main control system that allows the operator to set parameters that control the boom, the pump and a variety of other functions to enhance convenience, performance and overall ease-of-use.


“The Ergonic system modules are housed conveniently in one location by the modular control box,” notes Travis Nonn, technical service engineer for Putzmeister America.

The modules include Ergonic Pump Control System (EPS) for the pump and various operational functions, Ergonic Boom Control (EBC) and Ergonic Tele Service (ETS) for remote diagnosis of computer fault codes.

“The Ergonic system features EBC with OneTouch™, which many customers are familiar with,” says Nonn. “This module helps ensure minimal boom bounce while providing enhanced safety and easier control. OneTouch enables the operator to use a single joystick on the radio remote to automatically move all boom sections and slewing in tandem while keeping the end hose level and the boom within prescribed maximum and minimum heights.”

Another module of the Putzmeister Ergonic technology is EPS. EPS includes an Ergonic Graphic Display (EGD), featuring a three-inch square LCD screen which allows the operator to both view functions from the unique modular control box and change selected pump settings such as stroke time, hydraulic pressure, engine rpm and more. This module also includes Ergonic Output Control (EOC), which automatically controls optimum engine rpm while ensuring the lowest possible fuel consumption, reduced wear and low noise levels.

“ETS is the newest Ergonic feature, allowing the Putzmeister customer support group to wirelessly access and troubleshoot any problems that may occur with the Ergonic computer systems,” notes Nonn. “With this setup, our technicians can check the Ergonic computer systems remotely anytime the truck is in PTO mode. This includes viewing engine rpm, stroke time, high pressure, pump output, oil temperature, boom cylinders pressure, boom position, radio remote functions, operating hours and fault histories. Whether we’re at our headquarters or in the field, this makes addressing issues for our customers more immediate.”

For more details, contact Putzmeister America toll-free at (800) 884-7210, (262) 886-3200 or visit the company’s web site at [www.putzmeister.com](http://www.putzmeister.com). 



## OBITUARIES

### JOHN R. STUBBLES

John R. Stubbles, a noted steel industry consultant in Mason, OH, and leader in the realm of energy technology and savings, has died in Essex, England. He was 75.

Stubbles was educated in England, receiving a bachelor of science degree in metallurgy from Manchester University in 1954 and a doctorate in chemical metallurgy from London University in 1957. After six years in academia, he joined Youngstown Sheet & Tube Co., Youngstown, OH, and for the next 36 years managed technical activities both at integrated steelmakers and a mini-mill. He retired in 1999 to become a private consultant to the steel industry and organizations, such as the Steel Manufacturers Association, and the U.S. Department of Energy.

A respected author and lecturer, he was active in the Iron and Steel Society for more than 40 years and was a member of its successor organization, the Pittsburgh-based Association for Iron and Steel Technology (AIST).

“He had a great innovative mind. He was a tremendous contributor to the steel industry. He certainly will be missed,” Thomas A. Danjczek, president of the SMA, said.

“John was a 51-year member of the AIST and his passing represents a significant loss for our membership. Throughout his enduring career, John served the steel industry as an academic, practitioner, intellectual and historian,” said Ron Ashburn, president of the AIST. “Since his retirement from active employment in 1999, John has passionately pursued a logical, fact-based approach towards achieving a realistic energy policy for the U.S., taking into account our natural resources, allocation needs as well as our goal for energy independence.” *By Scott Robertson Published: Oct 1 2009*

### DAVID A. KNOWLTON

David A. Knowlton, 71, of Wheelersburg, died at SOMC Hospice on Tuesday, Sept. 22, 2009.

He was born June 20, 1938, in Washington, D.C., to John and Emma (Miller) Knowlton Sr. David graduated from Bethesda (Md.) High School Class of 1956, Capital University, and Ohio State University with a Ph.D. in Philosophy. He served in the U.S. Marines from 1961 to 1971 and was honorably discharged with the rank of captain. David was a member of the American Ceramics Society, the Sciotoville United Methodist Church’s Men’s Group, and the Society of the Sigma Xi. He enjoyed his involvement with church, woodworking, computers, music, and most especially spending time with his children and grandchildren.

In addition to his parents, he was preceded in death by one brother, John Knowlton II.

David is survived by his wife, Kathy Hamilton Knowlton; two sons, Kenny (Sarah) Knowlton of Cincinnati and Chad (Heather) Potts of Circleville; one daughter, Stacy (Doug) Bragg of St. Louis, Mo.; four grandchildren, Taylor Potts, Lesley Knowlton, Logan Potts, and Sophie Bragg; many special nieces and nephews.

Funeral services were held on Friday, Sept. 25, 2009, at Christ United Methodist Church in Sciotoville, with Pastor Frank James officiating. Interment was in South Webster Cemetery. Wolfe-Nelson Funeral Home in Sciotoville handled the arrangements.

# WHAT AFFECTS EROSION RESISTANCE OF REFRACTORY CASTABLES?

V. A. A. dos Santos, L. R. G. Gonçalves, J. Gallo<sup>1</sup>, J. Medeiros<sup>2</sup> and V. C. Pandolfelli

Materials Microstructural Engineering Group – GEMM, Materials Engineering Department, Federal University of São Carlos, Rod. Washington Luiz, km 235, São Carlos, SP, Brazil

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## ABSTRACT

The wear of refractory linings is often a critical problem in process units where transfer lines are subjected to high velocity gas stream containing solid particles. Knowledge regarding erosive wear of refractory linings under these conditions is restricted and, as consequence, the technological development is slow and, in general, carried out in an empirical way.

The objective of the present work is to review relevant aspects related to erosive wear in industrial applications and to investigate the erosion resistance of refractory castables currently used by the aluminum industry and in petrochemical cracking units. Among the erosion variables tested are: the particle impingement angle, line pressure, particle size and hardness, the microstructure of the refractories, the binding agent content, type of aggregate, thermal history and porosity.

It was found that the higher erosion was attained at 90° of impingement and decreased slightly when the angle was close to 30°. The results also pointed out that erosion was proportional to the particle velocity, its hardness and size. In addition, it was observed that the refractory erosion resistance is mostly affected by reducing the porosity.

## INTRODUCTION

Refractory castables are commonly used to provide erosion resistance at the working temperature. In the aluminum industry, for instance, they are mainly presented as linings in aluminum hydroxide calciners. In fluid bed stationary calciners, hot transfer lines and cyclone separators have to withstand erosion of particles conveyed at approximately 30 m/s and temperatures as high as 1200°C [1]. Similar conditions are found in cyclones and catalyst transfer lines of petrochemical cracking units [2], where plastic refractories and castables are used. To reduce the maintenance costs and the risk of unplanned production stopping, refractory castables with improved erosion resistance are required.

In this paper, some concepts concerning the preliminary developments of erosion resistance of refractory castables will be presented. Current problems found in the aluminum industry and in catalyst cracking units are shown to provide a basic understanding regarding erosion. Finally, results of erosion testing of refractory castables are shown and discussed.

## Erosion in industrial applications

The selection of the suitable wear resistant lining will depend on various factors including the operational life extension provided by the material, overall cost, design parameters of the system, dimensions of the lining area, the media being conveyed, flow rates and chemical attack [3].

Erosion is defined as the progressive loss of original material from a solid surface due to the mechanical interaction between the surface and a fluid, i.e. impinging liquid and/or solid particles [4]. Due to the broad range of these definitions, ASTM suggests that the wear mechanism has to be indicated, which in this work could be stated as erosion by solid particle impingement.

Erosion is detected in industrial applications where high particle velocities and turbulence of flowing liquids and gases are found. Erosion starts to become a problem when the gas velocity is about 3 m/s, and it is very severe, even for low particle concentration, at velocities as high as 36 m/s [5].

In fluid bed stationary calciners for aluminum industry or cracking units in the petrochemical industry, sudden changes in gas flow direction are required. As result, erosive particles impinge on internal walls of transfer lines at high velocities, causing wear. Modifications in the equipment project aiming at reducing particle velocities and improvements in refractory linings helps to increase life expectancy of the equipment. However, these changes are mostly infeasible, pointing out the need for refractory castables with superior wear resistance.

## Erosion of materials

Parameters that control wear include the properties of the carrier fluid, those of the particles themselves, and the properties of the target material [1]. This work concerns the last two items.

The particle parameters that influence erosion include particle shape and size, density, the particle velocity, and the angle of the particle impingement. The relevant properties of the target material include the microstructure, the toughness, and the hardness. According to Ruff and Wiederhorn [6], the most important experimental parameter that controls erosive wear is the particle velocity.

Investigations of the properties of the target material are concentrated in two areas of study: the hardness of the target [7] and the

flaws on the surface of brittle materials [1]. Oh [8] suggests that surface cracks are the nuclei for larger ones which are formed during erosion. Therefore, the distribution and depth of the surface crack influence the erosion rate. To support his arguments, the author has related the erosion rate to the Weibull parameters which express the flaw size distribution in the material [9]. Thus, clear evidence that the surface quality is an important factor in erosive wear can be shown.

The influence of the hardness of the target material is the differential factor among the developed models for brittle ones, as presented later in this paper.

## Science of Erosion

Impact by sharp particles (angular rather than round) results in a different type of crack pattern in the target surface. Two types of cracks are observed: the first is a radial set of cracks oriented primarily perpendicularly to the target surface; the other is a lateral set of cracks parallel to the target surface (**Figure 1**). The radial set of cracks is primarily responsible for strength degradations, whereas the lateral ones are responsible for erosive wear.

Two of the most accepted models of erosion developed for brittle material were proposed by Evans [11] and by Wiederhorn – Law [12]. Both models assume that particle impact is normal to the target surface and that erosion is the result of cumulative damage of no interacting, single particle impacts. Moreover, the models are based on the assumption that erosion occurs entirely by crack propagation and chipping. The main difference between the models is the contribution of the plastic deformation to the process of crack formation.

The model developed by Evans [11] assumes that the erosion rate is proportional to the amount of material withdrawn by each impact event. The volume lost ( $V$ ) per impact is calculated from the depth of penetration and the maximum size of the lateral cracks formed during impact. Therefore, the following equation is obtained for the erosion rate:

$$V \propto v_0^{19/6} \cdot r^{11/3} \cdot \rho^{19/12} \cdot K_{IC}^{-4/3} \cdot H^{-1/4} \quad (1)$$

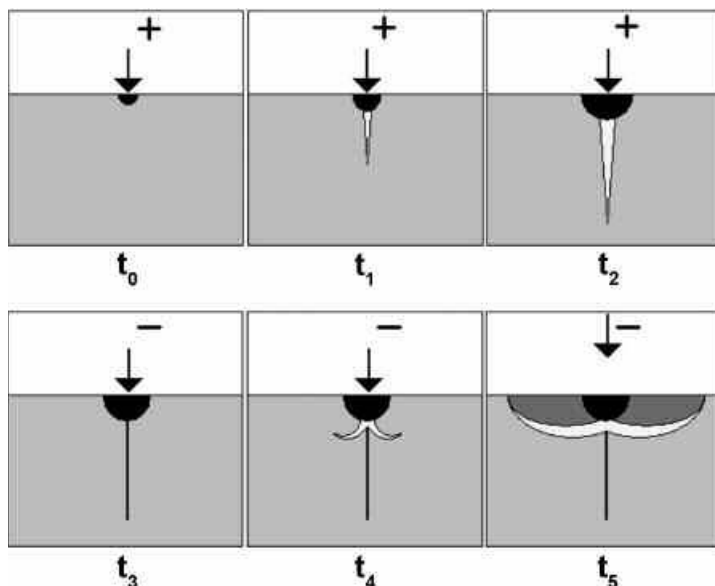
where:

- $V$ : volume lost ( $m^3$ )
- $v_0$ : particle velocity ( $m/s$ )
- $r$ : particle radius ( $m$ )
- $\rho$ : particle density ( $kg/m^3$ )
- $K_{IC}$ : critical stress intensity factor of the target material ( $MPa \cdot m^{1/2}$ )
- $H$ : hardness of the target material ( $GPa$ )

The elastic plastic theory used by Wiederhorn – Law [12] can also be applied to the development of an erosion theory. Assuming that the lateral crack size is proportional to the radial crack size and that the depth of the lateral cracks is proportional to the maximum particle penetration, then the wear rate is given by the following expression:

$$V \propto v_0^{22/9} \cdot r^{11/3} \cdot \rho^{11/9} \cdot K_{IC}^{-4/3} \cdot H^{1/9} \quad (2)$$

This theory is more suitable for high temperatures, considering that the wear is carried out by both mechanisms: ductile, based on the plastic flow; and brittle, with microcrack formation.



**Figure 1.** Shows crack growth during sharp impact. (+) indicates loading and (-) unloading. Dark area denotes irreversible strain [10].

Although the theory presented above is supported by erosion data, the functional dependence of this theory on others ceramic materials differs significantly. Considering the complexities of the erosion process, the simplifying assumptions used to derive models of erosion and those concerning dense ceramics, not refractory castables, additional theoretical and experimental work will be needed to further understand the refractory material erosion process. One of the reasons of this inequality is associated with the refractory materials microstructure, multi-phase composites consisting of a matrix paste surrounding a cluster of coarse aggregate grains [13].

## “Shadowing Effect”

Fully developed erosion surfaces show a somewhat different behavior from the reported model above. The main theory which describes the erosion of refractory castables is known as the “shadowing effect” [14]. In the present model, the aggregate grains were approximated by spheres. Thus, only the matrix phase among the spheres is eroded by a direct impact of the erosive particles. As the matrix phase is eroded, canals are developed exposing the aggregate grains, which protect the matrix phase through the “shadowing effect”.

This model suggests that the dependence between erosive wear and the impingement angle is determined by the size and spacing to the largest aggregate particles in the refractory, as illustrated in **Figure 2** and according to **Equation 3**.

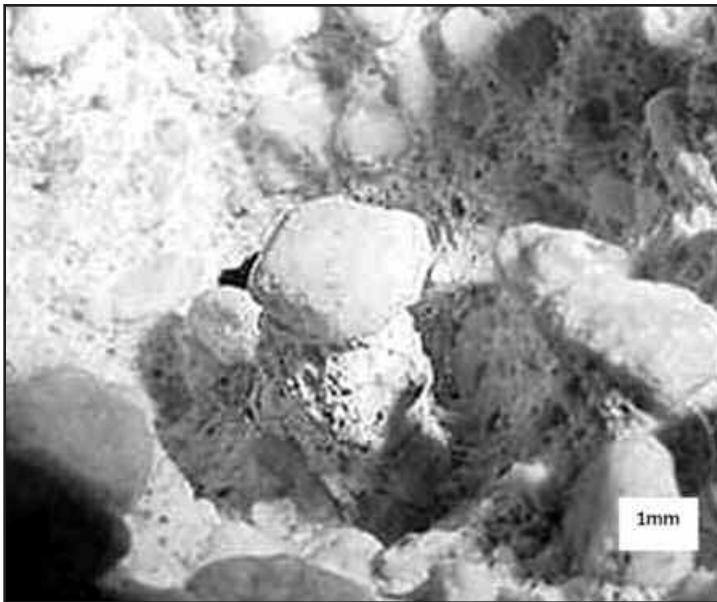
$$A = 2 \cdot (1 - R/\sin\alpha) \quad (3)$$

where:

- $A$ : total available area ( $mm^2$ )
- $R$ : aggregate grain radius ( $mm$ )
- $\alpha$ : angle of impingement ( $^\circ$ )

## Erosion and Porosity

It is generally assumed that the wear behavior of the refractory castables is controlled by the strength of the material, and that any



**Figure 2.** “Shadowing effect” where the aggregate is protecting the underlying matrix.

change in this property will be followed by a corresponding one in the erosion rate [15].

The strength of ceramics can be understood in terms of the Griffith [16] equation of strength:

$$\sigma_f = 1/Y \sqrt{2 \cdot E \cdot \gamma_{eff} / \pi \cdot C} \quad (4)$$

where:

$\sigma_f$ : strength (MPa)

$\gamma_{eff}$ : fracture energy per unit area necessary to initiate failure propagation (J/m<sup>2</sup>)

E: Young’s modulus (GPa)

C: flaw size

Y: dimensionless constant

**Equation 4** predicts that the strength of ceramics is mainly controlled by two variables, fracture energy and flaw size. Both parameters depend strongly on the microstructure. Thus, microstructural parameters, such as porosity, fulfill an important role in the strength of the material.

Porosity is deleterious to the flexural strength for two reasons: pores reduce the cross/sectional area across which a load is applied, and they also act as stress concentrators. Experimentally, it has been shown that the flexural strength decreases exponentially with the volume fraction porosity [17].

As a consequence, porosity has also been shown to affect the wear behavior, where increased porosity leads to degradation in the wear resistance [18]. A feasible option to reduce porosity is the use of substances known as glass former, a raw material responsible for the formation of liquid phases during the firing process. A highly effective glass former is the borosilicate frit, a material which has BO<sub>3</sub> planar triangles and SiO<sub>4</sub> tetrahedron linked to form networks, which generates glass with lower melting temperatures and a broader working viscous range. This melt should form a dense layer, reduce porosity and improve the toughness of the material.

## MATERIALS AND EXPERIMENTAL PROCEDURE

Four different types of materials were chosen for the present work. Aluminosilicate bricks (B), soda-lime glass (G), erosion resistant commercial available plastic refractories (PA, PB and PC) and a high alumina refractory castable (C) developed by the research group where this work was developed [19].

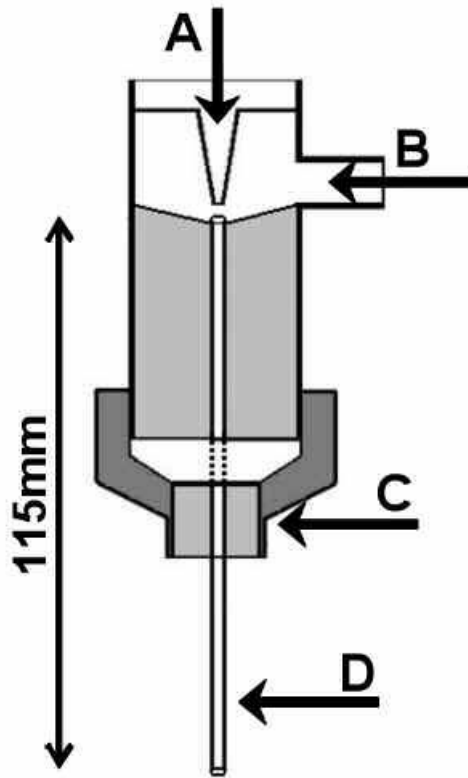
Erosion tests were conducted at room temperature (ASTM C 704 [20]) using the samples with the following dimensions 115 x 115 x 25 mm<sup>3</sup> [21]. The experimental procedure used in this work can be divided into three distinct stages: equipment accuracy, specimens’ preparation and analysis of erosion resistance as a function of some parameters, such as operational characteristics, materials properties and their thermal history.

### Equipment Description

The erosion equipment is illustrated in **Figure 3**, where the essential components consist of a metal chamber, a feeding mechanism and the air pressure and sand blast devices. A schematic diagram of the sand blast mechanism is shown in **Figure 4**, consisting basically of an air nozzle (A), an erosion media inlet (B), a stabilizing sleeve (C) and the glass tube (D). The glass tube must be replaced after each test in order to avoid changes of its internal diameter and of the corresponding pressure.



**Figure 3.** Erosion test equipment [22].



**Figure 4.** Sand blast device: (A) Air nozzle; (B) Erosion media hole; (C) Stabilizing sleeve; (D) Glass tube.

### Equipment Accuracy

In order to ensure the tests' reproducibility, erosion experiments were performed using soda-lime glass standard specimens. This material was chosen due to its homogeneity and zero porosity. Results obtained showed good reproducibility ( $4.92 \pm 0.04 \text{ cm}^3$ ), since the maximum result difference between two tests in this material using the same equipment was  $0.5 \text{ cm}^3$  [22].

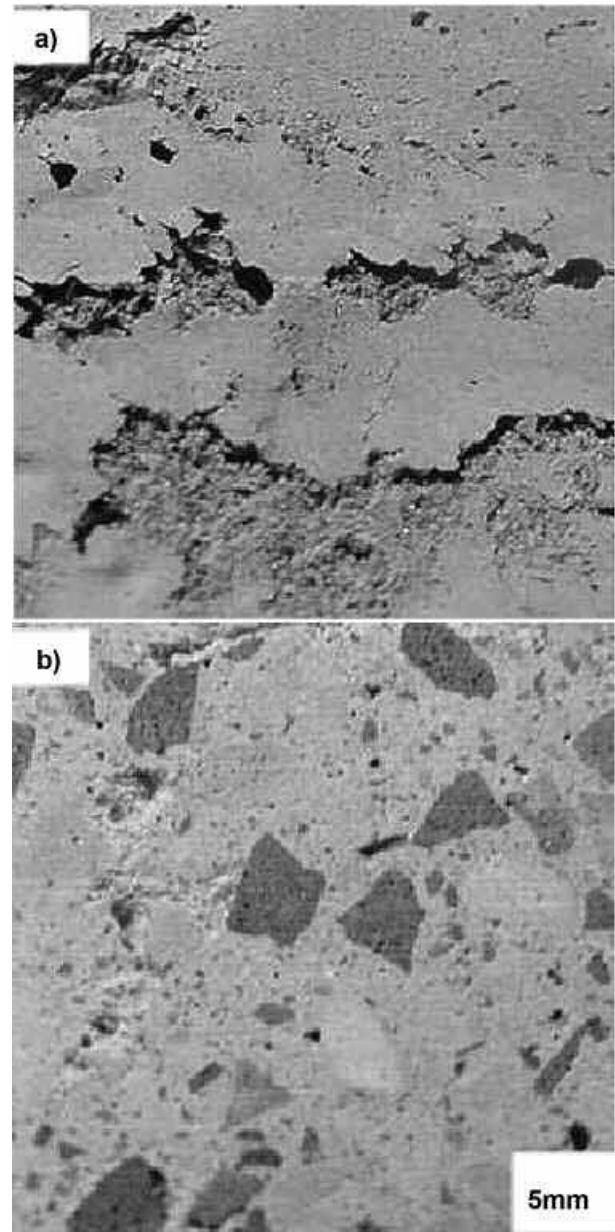
Silicon carbide particles (EC6-F036, Treibacher Schleifmittel, Brazil) used in this work were dry sieved according to the ABNT standard [23] in the size range of 300 – 600  $\mu\text{m}$  to ensure the correct particle size distribution.

### Preparation of Specimens

Plastic refractories were mixed using a rheometer developed for refractory castables [24] and molded. The specimens were cured for 24 h at room temperature and dried for 24 h at  $110^\circ\text{C}$ . For castable refractory specimens', curing was conducted for 24 h in an environment kept at  $25^\circ\text{C}$  and  $\sim 100\%$  relative humidity.

Engman [25] demonstrated that, due to the "shadowing effect", the erosion testing of a heterogeneous material might have different results depending on the region in which the testing takes place. It is suggested that the testing must reach a depth where the measured average wear rate is almost independent of these heterogeneities.

Specimens were wet-ground in order to expose the internal microstructure of the material and to obtain a steady-state erosion behavior [8, 25], as illustrated in **Figure 5**. After that, specimens were dried for another 24 h at  $110^\circ\text{C}$ . Based on previous work conducted by the authors, it was concluded that these refractories are not affected by wetting during the grinding process.



**Figure 5.** Pictures of (a) not ground and (b) ground surface of the specimens.

### Erosion testing parameters

An understanding of how the erosion is affected by its parameters is a primary requirement in the search for knowledge about erosive wear. Therefore, the effect of the line pressure, impingement angle, size and hardness particles on erosion phenomena were examined.

Aluminosilicate bricks (B) and the plastic refractory (PA) – soft and hard materials, respectively – were eroded at a distinct line pressure. In this case, changes in pressure will induce particle velocity shifts. Erosion measurements of this plastic refractory as a function of the particle impingement angle (using a holder that allows the specimen to be tilted to any desired angle) and of the size and hardness of the particles were evaluated, as the importance of the particle hardness has also been recognized in the literature [26]. Silicon carbide, calcined alumina (A1, Alcoa, Brazil) and aluminum hydroxide (C-30, Alcoa, Brazil) were used as erosive media for this study.

## Erosion as Function of Materials Properties

In order to understand the influence of binding agent content in the erosion resistance, high-alumina castable compositions were formulated with various calcium aluminate cement contents (2, 5 and 10 wt%). All castables were carefully designed with the software PSDesigner [27, 28].

A comparative study to evaluate the influence of the aggregates on the wear behavior was carried out. Two high-alumina castable compositions were prepared with 10 wt% of calcium aluminate cement and distinct types of aggregate grains: brown and white fused alumina supplied by Elfusa Brazil.

Afterwards, the effect of thermal history of the castables and plastic refractories erosion resistance was evaluated in order to detect whether the materials tested presented any significant change of the binding agent performance. The heating rate and the dwell time were 1°C/min and 5 h, respectively.

In addition, samples of aluminosilicate bricks (B), soda-lime glass (G), erosion resistant commercial available plastic refractories (PA, PV and PC) and a high alumina refractory castable (C) were erode tested and their apparent porosity was measured by water immersion according to the techniques described by the ASTM C-20 standard test method [29]. Specimens of alumina refractory castable compositions with distinct contents of borosilicate frit (0, 1, 3 and 5%) were also evaluated, aiming at a more consistent relation between erosion rate and porosity.

## RESULTS AND DISCUSSIONS

### Erosion Testing Parameters

Figure 6 presents the effect of the line pressure on the volume loss of different erosion resistant materials (PA and B). Material B is not designed for applications where high erosion resistance is required, as it presents high porosity and crystalline and amorphous phases of low hardness. The harder material – PA – showed less susceptibility to the line pressure [30].

Based on these results, the pressure of 400 mm Hg was selected as a standard value because it imposes a more severe condition among those analyzed. Furthermore, it is the suggested value for ASTM C 704 [20].

The effect of the impingement angle on the volume loss of material PA is shown in Figure 7. Erosive wear is the highest when the

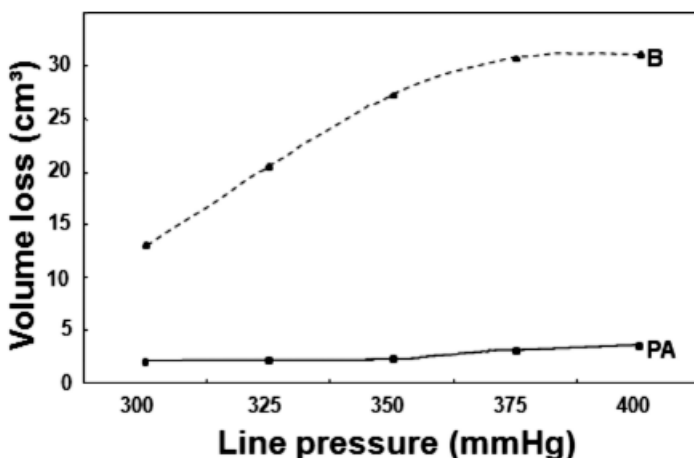


Figure 6. Effect of line pressure on volume loss of distinct erosion resistance materials (B: Aluminosilicate bricks and PA: plastic refractories samples).

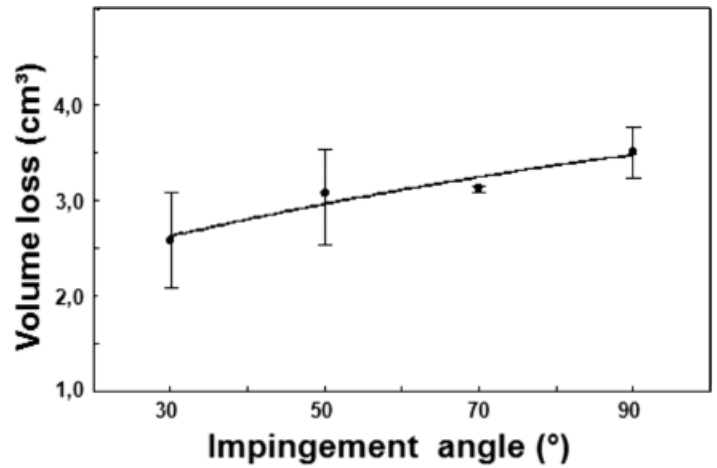


Figure 7. Effect of impingement angle in volume loss of plastic refractory material PA.

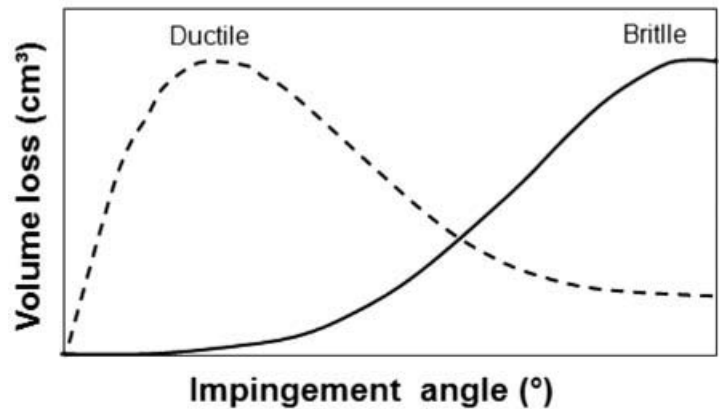


Figure 8. Erosive wear of ductile and brittle materials as a function of the angle of impingement [6].

angle of impingement is 90° and the erosion decreases gradually as the angle changes from 90° to 30°. This behavior is quite similar to that reported elsewhere for refractory castables and for glass [31], although in the case of glass, the erosion rate is observed to decrease more rapidly. Thus, the erosion behavior of the refractory castables is typical of brittle materials (Figure 8) showing little or no plastic deformation at room temperature.

Deviations of 10% among the results are acceptable because of the inherent heterogeneity of the castable and plastic refractory specimen microstructure. Materials with superior erosion resistance had a very small weight change, and consequently, the loss of a single grain of aggregate during the test changes its volume loss appreciably. As the impingement angle decreases, usually, increasing deviations were observed, mostly likely due to the smaller volume loss, resulting in not very precise results.

Reduction on the impingement angle leads to the formation of preferential wearing canals among the aggregates, as the matrix is worn out. However, as the impingement angle is below a critical value, these canals are protected by the aggregates – resulting in a decrease in the erosion rate.

Table 1 presents the properties of the erosive media: silicon carbide (SiC), calcined alumina (A1) and hydroxide aluminum (C30) and shows the effect of particle type on the erosion of material PA.

These results show that SiC has a more severe wearing. According to Equation 1, one possible reason for this behavior could be its high-

**Table 1. Properties of the erosive media**

	Bulk density (g/cm <sup>3</sup> )	Mohs Hardness	Particle size distribution (μm)			Volume loss (cm <sup>3</sup> )
			D10	D50	D90	
SiC	3.17	9.5	310	390	425	3.51
A1	3.5	9.0	55	95	150	0.17
C30	2.42	3.0	60	100	150	0.09

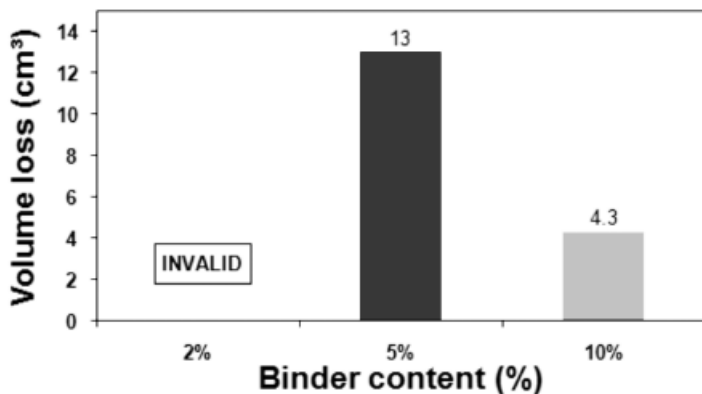
er particle size among the types of erosive media tested, although there is not a large difference in hardness between SiC and the calcined alumina particles. A decreasing particle size usually causes a lower volume loss; which may be associated to the lower kinetic energy of the small particles as they impinge the specimen [32]. The faced morphology of the SiC compared to the rounded ones of the calcined alumina might also have influenced the results.

Even though calcined alumina and hydroxide aluminum are alike in the particle size distribution, the former presents higher hardness and bulk density. Thus, a higher volume of material was eroded by the calcined alumina particles.

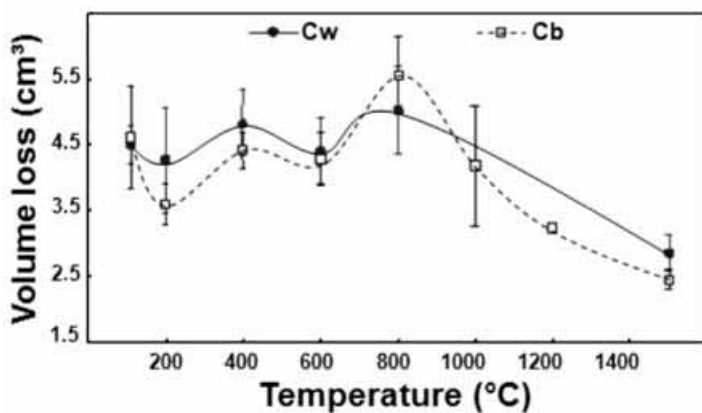
**Microstructural Parameters**

The influence of the binder agent content in the erosion resistance is illustrated in **Figure 9**. Tests performed with 2 wt% calcium aluminate cement were invalid since the erosive agent made a hole through the sample.

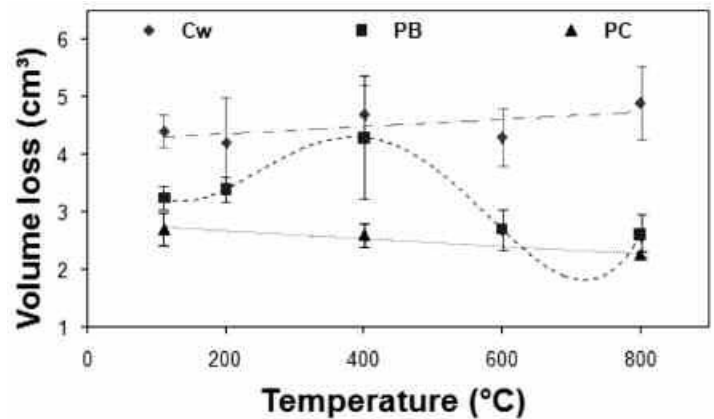
Results revealed that the erosion loss decreased with the cement content. This trend can be attributed, partly, to the increase in the matrix phase strength, holding the aggregates in place.



**Figure 9.** Effect of binder content in the erosion resistance.



**Figure 10.** Influence of the thermal history on the volume loss after erosion of two high-alumina castable compositions with distinct types of aggregate grains (Cw: white-fused alumina, Cb: brown fused alumina).



**Figure 11.** Effect of thermal treatments on erosive wear of a castable (Cw) and plastic refractories (PB and PC).

A comparative study of considering the aggregate nature is shown in **Figure 10**.

The effect of the thermal treatment on the volume loss after erosion was carried out for two high-alumina castable compositions with distinct types of aggregates: brown (Cb) and white (Cw) fused alumina. Although some differences in erosion resistance could be expected due to the distinct porosity of the grains, as shown in **Table 2**, this was not observed. Therefore, castable porosity provides a more consistent correlation with wear loss (**Table 2**).

The effect of the thermal treatment on the erosive wear of the castable (Cw) and the plastic refractories (PB and PC) was analyzed (**Figure 11**). Material PB presented higher volume loss when heat-treated at 400°C and an enhanced erosion resistance after 600°C and 800°C. These results point out the need for thermal treatment at temperatures higher than 400°C in order to maximize the erosion resistance of this material. The use of material C indicates the possibilities of saving energy, since its erosion resistance kept nearly the same level for the evaluated temperatures. However, if heat treatment would be required to fit it with other materials used in the equipment-lining project, heat treatment will not be detrimental. The erosion resistance of PC material had been enhanced by thermal treatment in the temperature range investigated.

**Figure 12** illustrates the relation between erosion loss and porosity of tested materials: aluminosilicate bricks (B), soda-lime glass (G),

**Table 2. Porosity of the distinct aggregates and of the refractories with these aggregates**

Alumina Type	Porosity of aggregates (%)	Refractory castable Porosity (%)
Brown Fused alumina	2.5	6.8
White fused alumina	7.0	7.0

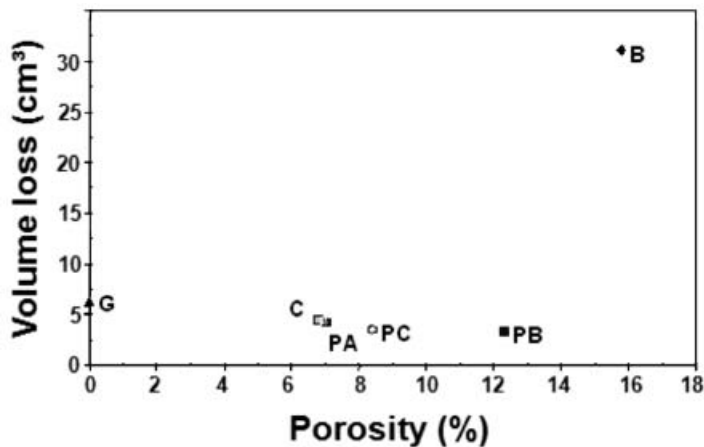


Figure 12. Erosion loss and porosity of tested materials.

erosion resistant commercial available plastic refractories (PA, PB and PC) and a high alumina refractory castable (C).

Even though glass does not present any porosity, the specimens resulted in lower erosion resistance than the evaluated plastic refractories and the volume loss was similar to the castable. Equation 1 can explain this behavior, since this material has lower values of hardness (H) and critical stress intensity factor (KIC), which could result in the formation and propagation of cracks after loading for long time intervals.

Although a close relation between the erosion rate and porosity would be expected, this was not observed. Plastic refractories presented very similar erosion resistance but distinct porosity values. One possible explanation for this behavior may be the different binding agents of these materials and, consequently, distinct hardness. Furthermore, the size and the mean distance among the coarse particles of each plastic refractory can influence the erosion resistance of these materials.

Figure 13 presents the effects of thermal treatment on the volume loss of alumina refractory castable compositions with different contents of borosilicate frit. The results attested the influence of porosity on the erosion for this castable class. Generally, the increase in the temperature leads to higher porosity values in the refractory castables with calcium aluminate cement, due to the dehydration of the binder [33]. This trend was modified by adding borosilicate frit, leading to the improvement of the wear resistance of the castables.

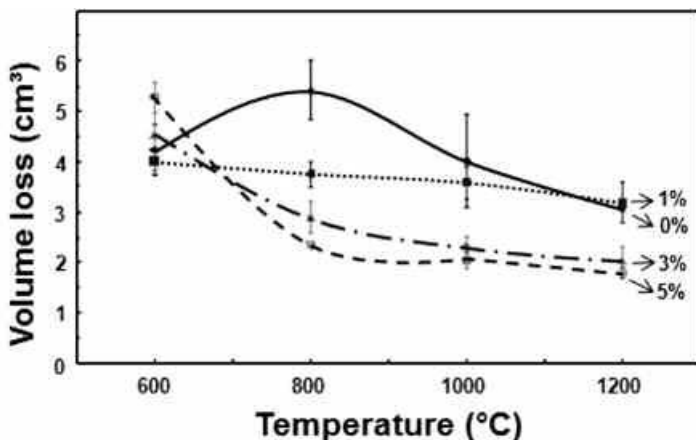


Figure 13. Effect of thermal treatment on volume loss of alumina refractory castable compositions with different contents of borosilicate frit.

## CONCLUSIONS

It was observed that some features of the erosion media particles and testing conditions including size, hardness, velocity and impingement angle, and the increase of any of these variables resulted in larger volume loss.

It is believed that the degradation in wear resistance is mostly due to the decrease in matrix bond strength and as a result the increased number of microstructural flaws that act as stress concentrators for nucleation and propagation of cracks. The thermal history of the material may cause changes in the binder efficiency and, consequently, a meaningful change in the erosion resistance.

Erosion resistance in commercial available plastic refractories evaluated in this work presented similar erosive wear resistance values. These materials have been an effective option to control wear by erosion in transfer lines of industrial units.


The addition of borosilicate frit may be an interesting choice for the erosive wear problem when porosity needs to be reduced. However, because at high temperatures it could induce liquid formation, it is important to identify the most suitable glass former type and content in order to avoid any detrimental aspects to the mechanical integrity of the refractory lining.

## ACKNOWLEDGEMENTS

The authors are grateful to the Brazilian research funding agency CAPES and to Alcoa Alumínio S.A., PETROBRAS, Elfusa Geral de Eletrofusão and for their support to this research.

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# VAST AMOUNT OF REFRACTORY INFORMATION ONLINE

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Charles E. Semler

Given the ever-increasing scope, content, and use of the Internet, with more, faster, and easier capabilities, such as WiFi, smart phones, texting, twitter (tweets), webcasts, global coverage, and much more, it is of interest to again review the general situation related to refractories, for comparison with my prior reviews in 2000 and 2003 [1, 2]. The Internet continues to provide increasing opportunities and benefits for all segments of the refractories world, with more to come in the future. The efficiency and productivity of management and workers are greatly enhanced, usually without having to leave their work site, and commonly with quick or immediate access to information or receipt of answers from anywhere in the world, without waiting for days/weeks. This article will mention a few of the Internet sites/sources pertinent to refractories, and show selected information there from, to indicate the current status.

tories world, with more to come in the future. The efficiency and productivity of management and workers are greatly enhanced, usually without having to leave their work site, and commonly with quick or immediate access to information or receipt of answers from anywhere in the world, without waiting for days/weeks. This article will mention a few of the Internet sites/sources pertinent to refractories, and show selected information there from, to indicate the current status.

## REVIEW OF SEARCH ENGINES

It is interesting to see the increase in number of “hits” on [www.google.com](http://www.google.com) between 2003 and 2009, as shown below; this comparison illustrates that there has been a big increase in information/data online, and this trend can be expected to continue.

Word Searched	2003	2009
Refractory	313,000	8,290,000
Alumina	234,000	7,020,000
Alumina Refractory	15,100	923,000
Fused Alumina	8,890	208,000

The table below shows the differences in the amount of information obtained from several of the available search engines:

Word Searched	Google.com	Bing.com	Ask.com
Refractory	8,290,000	1,750,000	1,350,000
Castable	272,000	182,000	46,600
Spinel Castable	179,000	8,070	11,300
Alumina Brick	3,710,000	186,000	345,000
Magnesia Brick	171,000	464,000	16,600
Bauxite	2,540,000	549,000	433,000

In the examples shown above, for most cases Google provided the most responses. Of course that refers only to the quantity of information and not necessarily the quality of the information. In all cases, the Google responses were received in less than 1 second; e.g., the 8.29 million hits for “refractory” were received in 0.23 sec.

## MONITORING THE STATUS OF STEEL AND REFRACTORIES

The performance of the steel industry is very important to the refractories industry because it is by far the major consumer (>60%) of refractories. So with the major recession that the U. S. and the world have endured, the steel industry has been directly impacted with significant reductions in production, with an obvious direct negative effect on the refractories industry, and their suppliers. Some examples of steel industry websites are [www.worldsteel.org](http://www.worldsteel.org) (World Steel Organization), [www.steel.org](http://www.steel.org) (American Iron & Steel Inst.), [www.aist.org](http://www.aist.org) (American Inst. of Steel Technology) [www.steelguru.com](http://www.steelguru.com), and [www.metalsplace.com](http://www.metalsplace.com). And when reviewing/using websites, always note what links they include to other pertinent sites. For example, the [aist.org](http://aist.org) site includes links to 19 refractory websites.

Based on data from [worldsteel.org](http://worldsteel.org), **Figure 1** (World and China) and **Figure 2** (Japan, U. S., Russia, and India) show the steel production for the world and the top-5 steel-producing countries in 2008 and 2009 (to date). Per these data, the following table shows the timing of steel production changes for the world and the top-5 steel-producing countries in 2008 and 2009 (to date):

	Production Decrease	Production Increase
World	June '08	January/March '09
China	July '08	December '08
Japan	June '08	March '09
U.S.	Sept. '08	March '09
Russia	Sept. '08	February '09
India	Production has remained relatively stable for the period.	

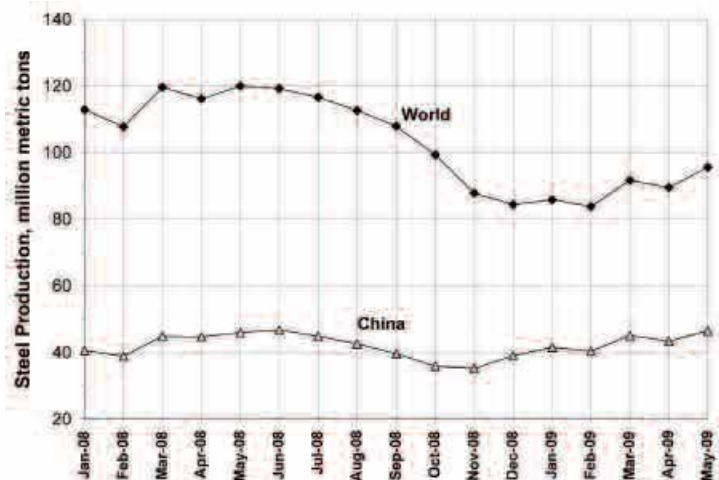


Figure 1. Steel production for the World and China (#1 producer) for 2008, and 2009 (to date).

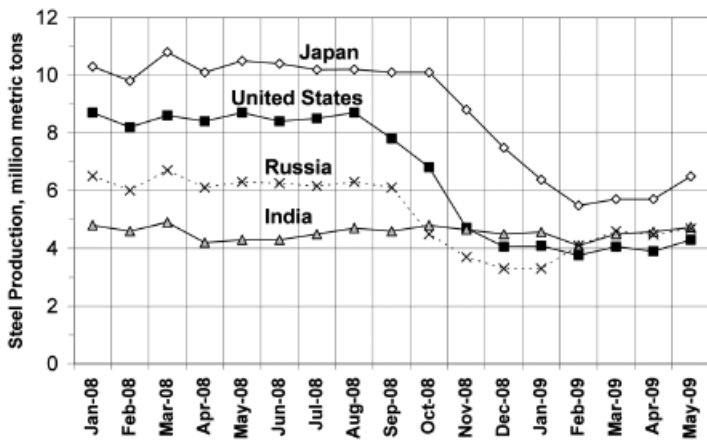


Figure 2. Steel production data for the world's #2 through #5 producing countries for 2008 and 2009 (to date).

Current Industrial Reports. The 2008 Census report showed the following annual value for the U. S. refractory production for the last five years:

Year	Clay Refractories*	Nonclay Refractories*	Total Market Value*
2008	989,223	1,388,637	2,377,860
2007	964,699	1,304,493	2,369,192
2006	962,973	1,163,552	2,126,525
2005	860,844	1,152,700	2,013,544
2004	780,551	1,198,674	1,979,225

\*Value in thousands of US dollars

The U. S. Geological Survey (USGS) website, [www.usgs.gov](http://www.usgs.gov), provides annual reports about raw materials and commodities that pertain to refractories. Examples include bauxite, alumina, kyanite, clays, graphite, magnesite, iron & steel, iron & steel scrap, cement production, etc. The U. S. Patent office website, [www.uspto.gov](http://www.uspto.gov), offers the opportunity to find/read patents according to keywords or patent number. For example, searching this site for the word "refractory" yielded 49,911 hits in 2003, compared with 65,853 hits in 2009. Searching for refractory and alumina yields 19,780 hits, while castable results in 5,331 hits.

## OTHER SOURCES OF REFRACTORY INFORMATION

Most refractory companies and their suppliers, domestic and foreign, have websites which can be found in various publications and online. The refractory company sites commonly permit direct access to current news, published articles, product data sheets and MSDS, or they provide the opportunity to request the information. Some of these sites also permit meaningful analyses to be done, such as heat flow analysis, and characterization/graphing of particle size distribution.

A useful website for making instant contacts around the world, either verbal or verbal/visual (with a webcam), is [www.skype.com](http://www.skype.com). The cost is minimal or free, and at various times during the day, there will be 10 to 20 million people using Skype. Another site available for conducting online discussions/meetings is [www.gotomeeting.com](http://www.gotomeeting.com). And there are smart phones and other websites that offer the opportunity for making contacts anywhere in the world. And increasingly these options are being used to save time and reduce travel expenses.

Another option on many websites, is the availability of photos on virtually any subject. For example, on [google.com](http://google.com) and [bing.com](http://bing.com), a search for images of "refractory brick" instantly yielded 29,500 and 11,400 photos, respectively. And a request for photos of "castable refractory" resulted in 10,100 and 3,530 items, respectively.

In addition to [google.com](http://google.com), [bing.com](http://bing.com) and other sites, a very popular source for videos on virtually any subject, A to Z, is [www.youtube.com](http://www.youtube.com). A search for "refractories" videos immediately yielded 357 items, and there were 28 videos on "castables".

Technical associations and journals are valuable sources of refractory information; a few examples are, this journal, [www.ranews.info](http://www.ranews.info), the American Ceramic Society publications,

*Continued on page 20*

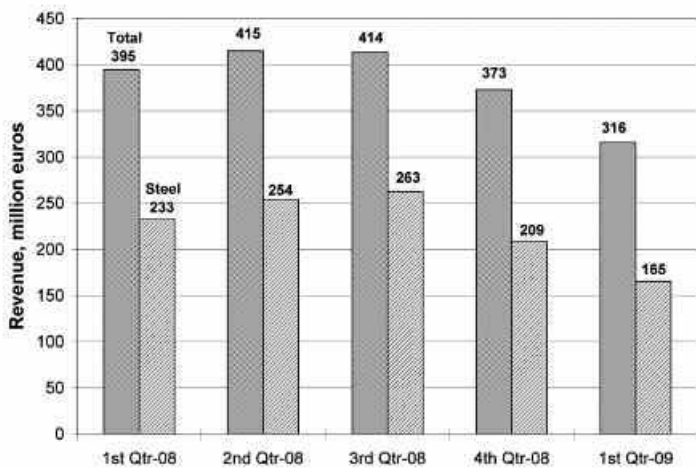


Figure 3. Plot showing the quarterly total revenue, and the revenue from the steel industry, for RHI AG (Austria) from Qtr.1 '08 through Qtr.1 '09.

It is significant to note in **Figure 2**, that the world order of steel producers has changed with the U. S. dropping from third to fifth, behind Japan, Russia, and India. And the comparison of '08 vs. '09 steel production ([worldsteel.org](http://worldsteel.org)) shows that China and India are the only major producers that are making more steel in '09, but only slightly at +0.4% and +0.5%, respectively, through May. The others all show less production in '09, as follows: World -22%, Japan -42%, Russia -32%, U. S. -53%.

An indication of the direct economic impact of the decrease in steel production on the world's largest refractory company, RHI AG (Austria) is shown in **Figure 3**, using data from their website, [www.rhi-ag.com](http://www.rhi-ag.com). It is seen that both the quarterly total revenue, and the quarterly revenue from refractory sales to the steel industry, declined in conjunction with the decline in steel production discussed above. These sales figures provide a relative measure of the direct affect of steel production on refractories business.

## SELECTED GOVERNMENT WEBSITES

There are a number of useful government websites that provide information pertinent to refractories. The Department of Census website, [www.census.gov](http://www.census.gov) publishes an annual report of the quantity and value of the U. S. production of clay and non-clay refractories; see Refractories in the alphabetical list of

# SILICA REFRACTORY: SOMETHING OLD THAT IS NEW

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Ruth Engel

When I started working in the refractory field, about 30 years ago, the brick qualities were completely different from what is currently available. Many of these changes have been driven by raw material availability and cost, and have resulted in a continuous improvement of properties. Additionally, demands for longer campaigns have also pushed for the use of new raw materials. For illustration purposes a loosely constructed and highly abbreviated time line for

alumina brick used in steel ladles, based mainly on personal experience, follows. In the late 70s and early 80s most steel ladles in the US were lined with bloating fireclay brick which had about 30%  $\text{Al}_2\text{O}_3$  (Schamotte is the European equivalent) and lasted for 12 to 15 heats before having to be replaced. The heats had minimal residence time in these ladles as this was before ladle treatment stations. In order to improve ladle life in the US, the brick quality was changed, first to 50%  $\text{Al}_2\text{O}_3$  and subsequently to 70%  $\text{Al}_2\text{O}_3$ . The raw materials went from fireclays to SEUS grain (South Eastern US bauxite, no longer available) and Guyanese bauxites (mine flooded, and this product was not available for many years; the mine has since been reopened). Because of availability and cost issues, these bauxites were supplanted by Chinese ones which led to major changes in properties and therefore ladle life. Subsequent changes have seen an increase in the overall purity of the raw materials, higher alumina levels, use of fused aluminas, additions of MgO and carbon to the brick. At the same time the residence time of each heat in the ladle increased anywhere from 60 to 180 minutes with the concurrent increase in temperature loading and stressing of the refractory as a result of ladle refining. Nevertheless, ladle life has increased manyfold. A similar progression has not been observed with silica brick.

Silica brick are one of the older refractories still in use and their expected properties have not changed over, at least, the last 50 years. Depending on whose summary is used the first silica brick are believed to have been made in ~1842 from Dinas rock in South Wales [1] or even earlier, in 1820 [2]. In the US the first such brick were produced around 1866, although a patent for the manufacture of lime bonded silica brick was already granted in 1858 [1]. The 1957 edition of *The Making, Shaping and Treating of Steel* [3] reflects the easy availability of raw material and the ubiquitous use of silica refractories in the US. It also states that “massive rock forms analyzing over 98%  $\text{SiO}_2$  are the chief raw materials for silica brick manufacture and are mined in Pennsylvania, Wisconsin, etc.” [3]. But 1957

also seems to have been a water shed year as shown by the next few quotes. In *Steelplant Refractories* [4], the author states that “although silica continues to meet severe competition from basic refractories ...it still maintains its position as the No 1 steelplant refractory...” and “In 1957 silica was still the number one steel plant refractory, even though it was meeting severe competition from basic Refractories” [1]. The eminent position of silica brick in steel making was about to change. Over the period 1947–1965 the US production of silica brick dropped to a third, as a result of the shutting down of the open hearth furnaces [1] and the use of other types of refractories. It is of note that although the steel industry is the major consumer of refractories, silica brick is also used in the glass industry which has made up for some of these losses.

The properties of silica brick were well established early on. In the early 1900 it was already known that silica ( $\text{SiO}_2$ ) is found in nature in one of three major forms: quartz, cristobalite and tridymite, nevertheless, much more work needed to be carried out to be able to elucidate the different relationships between them and how they affected the brick’s properties. By the 1950’s the technology for making silica brick was mature. In general, the expectation was that during manufacture of the brick the firing temperature would be sufficiently high to convert most quartz to either cristobalite or tridymite so the final product would have a consistent and small amount of permanent reheat expansion. Although a great amount of work can be found on the effects of different mineralizers on the rate of transformation of quartz to cristobalite and tridymite, most brick use only the originally determined small amount of lime for their bond. Silica brick are classified as KN (112 pcf or 1.79  $\text{gr}/\text{cm}^3$ ) or KD (116 pcf or 1.85  $\text{gr}/\text{cm}^3$ ) under the DIN 1089 standards [5]. ASTM C416 [6] presents another classification scheme, this one is based on a “flux factor” which is equal to the percent alumina plus twice the percent of total alkalis.

Silica brick’s physical properties are unique making them the optimum material for many installations. Camerucci, et al. (2008) [7] showed that the properties of the brick have not changed significantly over time even though different raw materials were used for their manufacture. Camerucci, et al. (2008) [7] compared the properties of unused 25 year old brick with newly manufactured ones and determined that they were equivalent and therefore could be used interchangeably.

Silica brick have good thermal shock resistance once they exceed 600°C. Generally, high purity silica brick form only a small amount of low melting point phases up to 1650°C after which they can fail rather quickly. Tests carried out to simulate use conditions should prevent catastrophic failures. Although the properties required have not changed, silica refractory manufacturing technology has evolved over time. Originally all that was available were small, often intri-


cately shaped brick which required very careful installation which took a long time to carry out. Currently, silica refractories can be obtained in brick or castable form. The latter has led to brick installations being replaced with precast shapes or even to be cast in place. The successful use of big precast shapes in place of the small and numerous brick which had to be painstakingly fitted together (example: part of a coke oven wall) has led to faster installations. In some cases whole walls are built out of a few precast pieces accomplishing a total replacement in hours instead of days [8]. In addition, changes in castable technology have also led to the possibility of cast in place installations.


In summary, major changes have taken place in the alumina silica refractory system because of the use of new raw materials and the demands for improved life. Over the same time frame, the chemistry and properties of silica refractories have remained constant although new raw materials have had to be found. The reason is that their properties are optimized for the application. The changes that have occurred can be found in the “manufacturing” processes in that developments in castable technology have expanded the brick size and installation choices available.

If you have comments about this column or suggestions for future topics please visit me at [www.refractoryexpert.com](http://www.refractoryexpert.com) and I will try to address them.

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*Vast Amount of Refractory Information Online Continued from page 18*


[www.ceramics.org](http://www.ceramics.org), *Refractories World Forum*, [www.refractories-worldforum.com](http://www.refractories-worldforum.com), *Interceram* (including the *Refractories Manual* issue), [www.interceram.info](http://www.interceram.info), and *Taikabutsu Overseas* (Japan), [www.tarj.org](http://www.tarj.org). The website for the next large international refractories meeting (Unified International Technical Conference on Refractories), in Salvador, Brazil, October 13-16, 2009, is [www.unitecr2009.org](http://www.unitecr2009.org); the program will include 240 papers, with attendees from around the world.

## SUMMARY

What a huge change since the days of dial phones, manual typewriters, carbon paper, onion-skin copies, snail mail, no overnight mail, lab-developed photos, hand-drawn graphs, and the many other standard operating practices (SOP) that we utilized in past decades. Now there are countless sources for obtaining information and making business contacts worldwide which have provided incredible increases in productivity and efficiency.

Given the space limitations, this article just skims the surface of the countless Internet options for doing business, obtaining information, and many other tasks. Clearly there are numerous other good and useful sites and sources in addition to those mentioned herein. The content of this article is not intended to promote or endorse any company or website. The author welcomes any comments from readers regarding use of the Internet for work, and favorite refractory-related websites, and if enough responses are received, a follow-up article will be considered.

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# ISOTHERMAL SECTIONS

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This installment of *Phase Rules* highlights the construction and utility of isothermal sections. Isothermal sections are actually a different “look” at a ternary phase diagram where the temperature is fixed at a desired temperature or isotherm. Although such diagrams are especially useful when considering containment of a liquid at a constant or relatively constant temperature, a series of isothermal sections can be constructed as well. Of course, a series of isothermal sections would miss some of the specific details, such as invariant reaction temperatures or state changes, but it would still provide a record of the equilibrium in the system.

The steps involved in construction of an isothermal section are quite straightforward but rather than describing them in a theoretical fashion, a previous ternary diagram is used as the backdrop. Building on diagrams used previously in the *Phase Rules* series [1-5] has been standard as the approach not only builds on previous concepts, it provides a simple view of how the various concepts can be combined to provide a more complete understanding of the equilibria in the system.

The MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system is used to detail the procedures involved in constructing an isothermal section. The ternary diagram is included as **Figure 1**. Recall that this diagram includes details from a large number of sources and should be one of the most comprehensive diagrams for MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> in the open literature.

The process of constructing an isothermal section for the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system begins, simply enough, by selecting the desired temperature and tracing along that temperature across all of the primary phase fields in the system. For instance, if the 2200°C isotherm was selected, the process would begin by tracing that temperature across the only phase field in which it is present, that being the magnesia primary phase field as shown in **Figure 2**. Any portion of the diagram that is below the temperature of interest can be ignored as it is now just part of the liquid region. In the 2200°C case, the liquid region encompasses most of the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> chemistries. The remaining region in the lower left corner of the diagram is a two-phase region bound by solid magnesia and liquid. The key is to

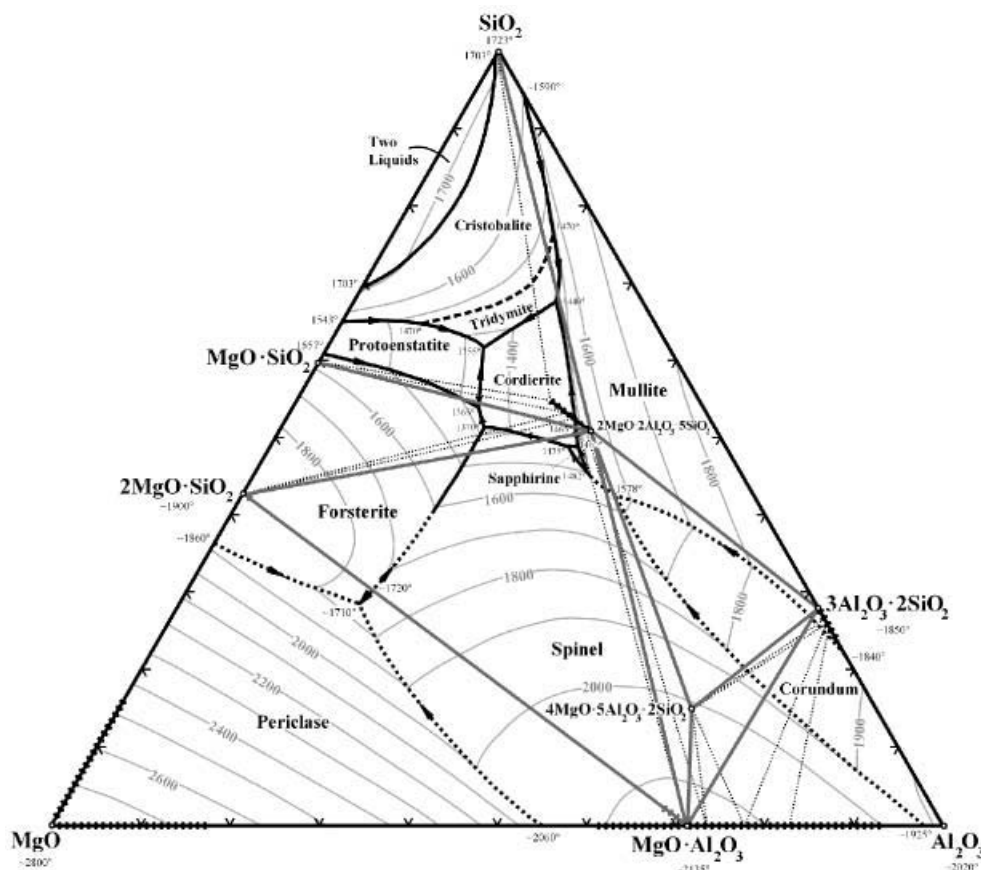
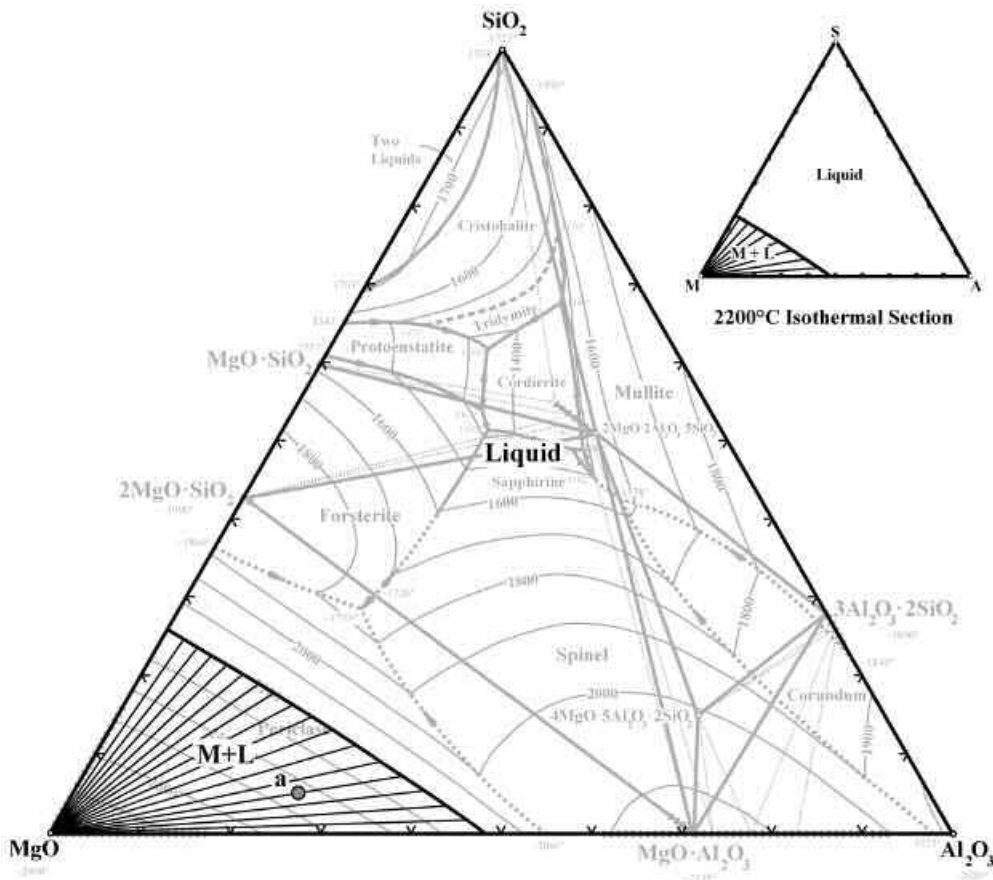


Figure 1. Phase diagram of the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system.



**Figure 2.** Construction of the 2200°C isothermal section from the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> ternary diagram.; small inset at upper right illustrates the result. (Note: point “a” is included for discussion in the text and is not part of the section.)

trace the liquid line through all of the phase fields, then consider each phase field separately, drawing a straight construction line from the end points of the liquid curve, back to the compound specified by the phase field. At 2200°C, any chemistry within the magnesia-plus-liquid region will obviously be a mixture of solid magnesia and liquid. The specific liquid chemistry that will be in equilibrium with the solid magnesia can be determined by constructing a straight line from the magnesia corner of the diagram through the chemistry of interest, until it contacts the liquid. The resulting line is a tie line connecting the two conjugate phases (analogous to the situation in binary phase equilibria) so the binary lever rule can be applied, with the starting chemistry as the fulcrum, to determine how much of each phase is present. Considering the chemistry of point **a** in **Figure 2**, the solid magnesia content is 30 wt% while the liquid is 70 wt%. The chemistry of each phase is specified by the ends of the tie line, with the solid chemistry being 100 wt% MgO and the liquid chemistry being determined by applying the ternary lever rule at the “liquid” end of the tie line. Using that procedure allows the 70 wt% MgO, 25 wt% Al<sub>2</sub>O<sub>3</sub>, and 5 wt% SiO<sub>2</sub> liquid chemistry to be calculated.

In this simple case of constructing the isothermal section for 2200°C, the liquid line only crosses the single-phase field. In most useful isothermal sections, the liquid would cross additional phase fields, but the procedure is the same. The only step remaining besides the omni-present labeling of the regions is to add all Alkemade lines. Recall that an Alkemade line is a line connecting two compounds that have a common boundary curve

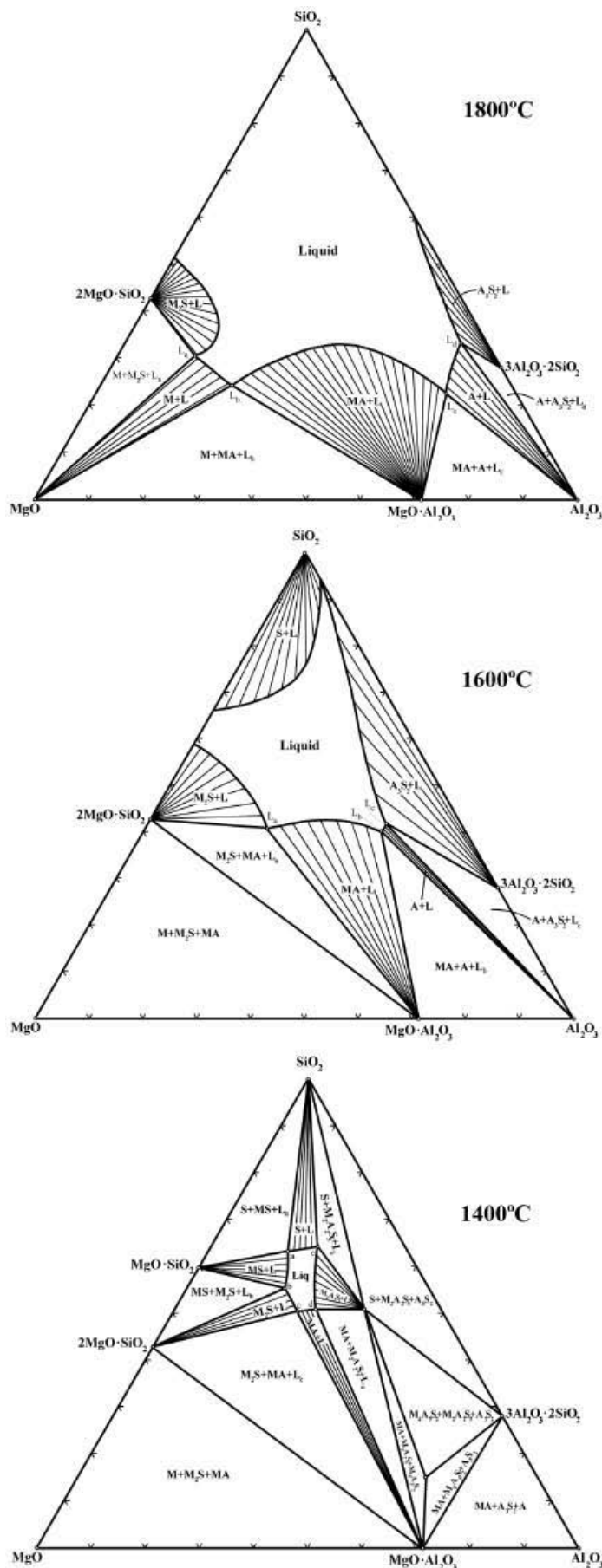
(i.e. the two components are stable together in the presence of liquid). Since no other phase fields are present in this simple case, there are no Alkemade lines to be included in the 2200°C isothermal section.

The lack of Alkemade lines in the example of **Figure 2** means that three phases cannot coexist at 2200°C. In cases where Alkemade lines are included, equilibrium between three phases must exist. The three phases can be either two solid and one liquid in equilibrium or three solids in equilibrium.

Once all the liquid curves are included, the ends of specific curves are connected back to the appropriate component and all of the Alkemade lines are added. The isothermal section is now complete.

A series of isothermal sections were constructed and are included as **Figure 3**. Temperatures of 1800°C, 1600°C, and 1400°C were chosen for this example. Considering the 1800°C section (**Figure 3**) it is obvious that curves were traced through the five phase fields that contained the 1800°C isotherm. The phase fields were forsterite, magnesia, spinel, alumina, and mullite. Constructing the lines from the ends of each of the five liquid segments back to the component of each of the five phase fields result in defining five regions that have a single solid in equilibrium with liquid. The largest of these regions is equilibrium between spinel and liquid.

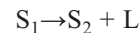
The final step of adding all Alkemade lines completes the isothermal section. At 1800°C, the phase fields of forsterite and magnesia share a boundary curve, as do magnesia and spinel,



spinel and alumina, and alumina and mullite. These four Alkemade lines complete four triangles on the 1800°C section. In all four cases, equilibrium is between two solids and one liquid, the largest being solid magnesia and spinel in equilibrium with liquid. The ternary lever rule can be applied to determine the equilibrium concentrations of the three at 1800°C for any composition within that triangle. It should be noted that the liquid composition remains fixed at point  $L_b$  for all chemistries within the triangle. In the case of the two-phase regions (one solid and one liquid) an infinite number of liquid chemistries could be in equilibrium with the solid but in a three-phase region (two solids and one liquid) only a single liquid composition can be in equilibrium. This effect results from losing a degree of freedom with the addition of a third phase.

The isothermal section for 1600°C is included as **Figure 3**. In this case, the section is only marginally more complex than the 1800°C section. When the Alkemade lines were included, a triangle (magnesia-forsterite-spinel) was isolated from the liquid region. The combination of three Alkemade lines to form an Alkemade triangle is an indication that three solid phases are in equilibrium. Any chemistry within that triangle would be solid at 1600°C and would consist of the three phases.

The 1400°C isothermal section is included as **Figure 3**. At this temperature, seven additional Alkemade lines are present, resulting in large part, from two ternary compounds that have peritectic temperatures between 1600°C and 1400°C. Both cordierite ( $2\text{MgO}\cdot 2\text{Al}_2\text{O}_3\cdot 5\text{SiO}_2$ ) and sapphirine ( $4\text{MgO}\cdot 5\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$ ) are incongruent compounds, meaning that neither solid melts into a liquid having the same chemistry. Instead, each compound dissociates into a solid and a liquid, each having a different chemistry than the compound itself. On heating, the general form of this peritectic dissociation is:



The additional Alkemade lines form five more Alkemade triangles, and as before, all chemistries within these triangles have solidified at a temperature between 1400°C and the previous isothermal section temperature of 1600°C. Applying the Alkemade triangle rule indicates (see **Figure 1**) that chemistries within the alumina-mullite-spinel triangle solidified at 1578°C, while chemistries within the other new triangles solidified at lower temperatures; mullite-sapphirine-spinel (1482°C), spinel-sapphirine-cordierite (1435°C), sapphirine-mullite-cordierite (1460°C) and mullite-tridymite-cordierite (1440°C). These temperatures are actually good indications of useful isothermal sections to construct. Selecting a temperature above and below each invariant point in the system would provide a complete record of the equilibrium.

In order to show the main utility of the isothermal sections, chemistries were indicated on larger versions of each of the diagrams as shown in **Figures 4, 5, and 6**.

Points **x** and **y** are included on the figures as points for discussion. The overall chemistry of **x** is 30 wt% MgO, 33 wt%  $\text{Al}_2\text{O}_3$  and 37 wt%  $\text{SiO}_2$  while point **y** is 7 wt% MgO, 46 wt%  $\text{Al}_2\text{O}_3$  and 47 wt%  $\text{SiO}_2$ . These chemistries were determined using the ternary lever rule as described in previous installments of this series.

**Figure 3.** Series of isothermal sections from the MgO- $\text{Al}_2\text{O}_3$ - $\text{SiO}_2$  system taken at 1800, 1600, and 1400°C.

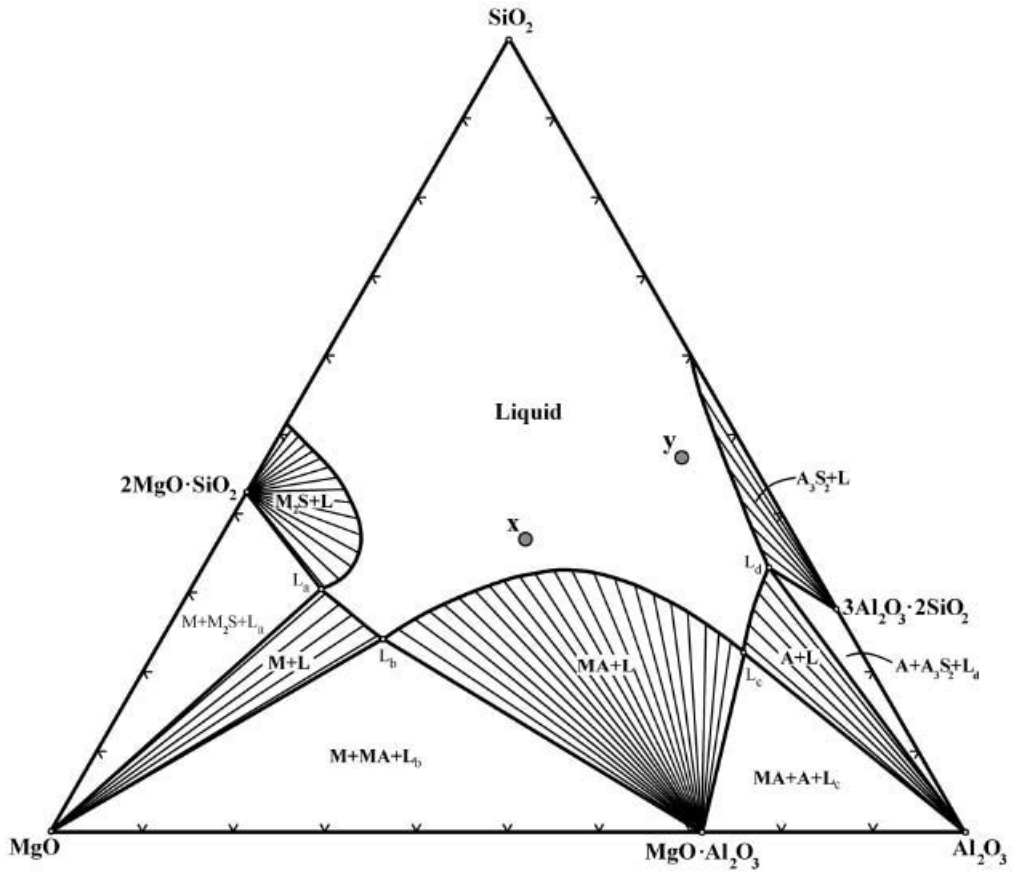


Figure 4. Isothermal section from the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> at 1800°C shown with chemistries at points “x” and “y” for discussion in the text. At this temperature, these two chemistries are molten.

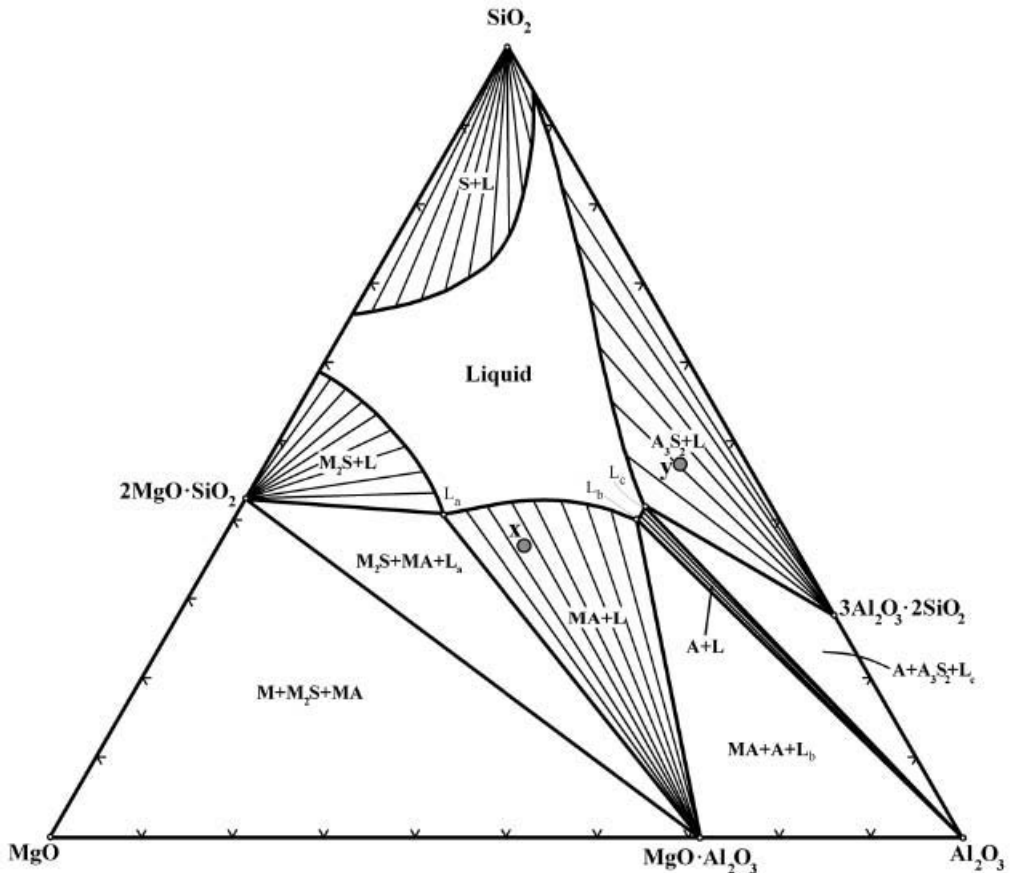
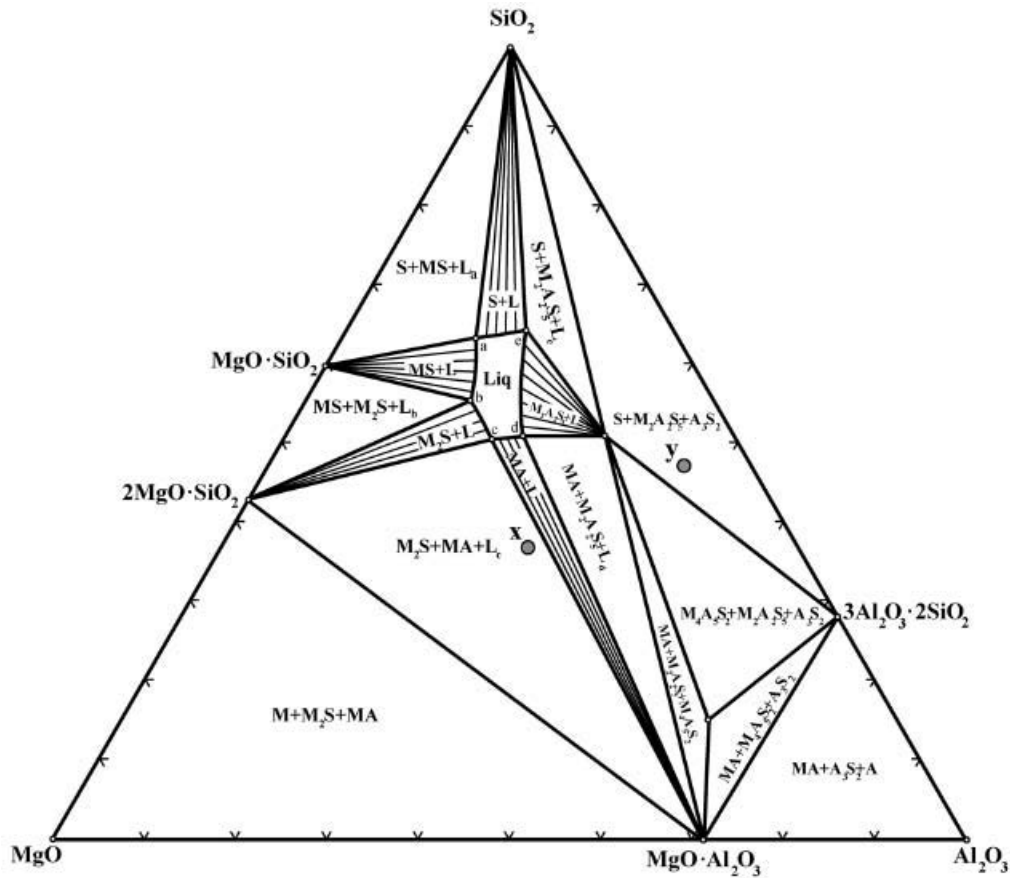


Figure 5. Isothermal section from the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> at 1600°C shown with chemistries at points “x” and “y” for discussion in the text. At this temperature, these two chemistries would exist as a solid in equilibrium with a liquid.



**Figure 6.** Isothermal section from the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> at 1400°C shown with chemistries at points “x” and “y” for discussion in the text. At this temperature, chemistry “x” exists as an assemblage of two solids in equilibrium with a liquid (L<sub>c</sub>), while chemistry “y” as an assemblage of three solids.

At 1800°C, as shown in **Figure 4**, points **x** and **y** are located in the liquid phase field, indicating that both chemistries are completely molten (100 wt% liquid). The liquid region at 1800°C is quite large encompassing all chemistries with greater than 60 wt% SiO<sub>2</sub> and most chemistries greater than about 35 wt% SiO<sub>2</sub>.

At 1600°C, as shown in **Figure 5**, the chemistry indicated by point **x** is located in the spinel-plus-liquid region. Repeating the same procedure that was used with **Figure 2** for determining the solid/liquid ratio yields 87 wt% liquid and 13 wt% spinel. By defining the overall composition and the temperature, only one liquid composition is in equilibrium. Using the ternary lever rule, that liquid composition is 30 wt% MgO, 28 wt% Al<sub>2</sub>O<sub>3</sub> and 42 wt% SiO<sub>2</sub>.

Similarly, the information related to point **y** can be determined. The chemistry is located in the mullite-plus-liquid phase field, it is comprised of 32 wt% solid and 68 wt% liquid and the liquid composition is 10 wt% MgO, 34 wt% Al<sub>2</sub>O<sub>3</sub> and 56 wt% SiO<sub>2</sub>.

Both chemistries were liquid at 1800°C and began crystallizing at some temperature between 1800 and 1600°C, defined by the liquidus point for each chemistry. With a chemistry of **x**, primary crystals of spinel begin to form at 1720°C while with a chemistry of **y**, primary crystals of mullite appear at 1710°C. In both cases, those crystals continue to grow in size as the temperature is lowered to 1600°C.

At 1400°C (see isothermal section included as **Figure 6**) the two chemistries are located within Alkemade triangles on the diagram, indicating equilibrium between three phases. In the case of chemistry **x**, the three phases are forsterite, spinel, and liquid; so at a temperature between 1600°C and 1400°C, forsterite and spinel crystallize simultaneously during cooling. At 1400°C, the overall phase assemblage is 9 wt% forsterite, 25 wt% spinel, and 66 wt% liquid. With a chemistry of point **y**, the three phases in equilibrium are mullite, cordierite, and tridymite. The absence of liquid

## GLOSSARY OF TERMS

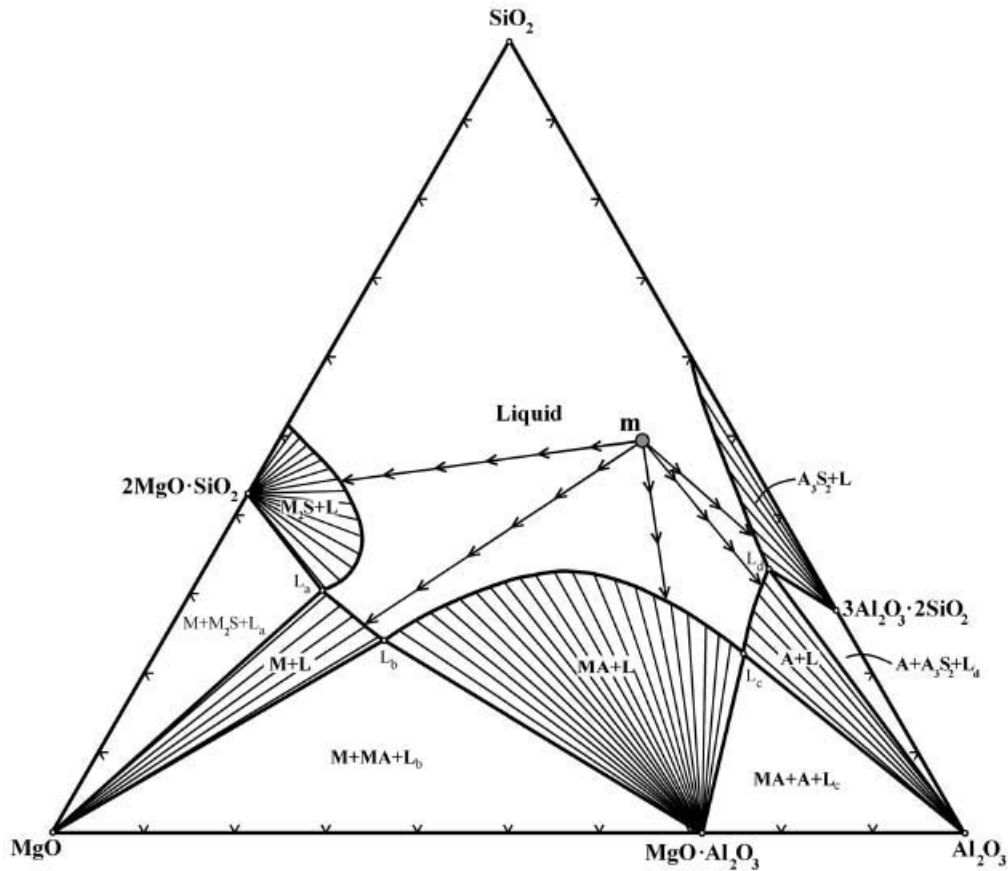
(refer to the previous installment [1, 2, 3, 4, 5] for additional terms of interest)

**Dissolution** – The process of a solid being dissolved and incorporated into a liquid.

**Saturation Limit** – The maximum amount of a substance that can be dissolved and incorporated into another at equilibrium. Typically this refers to the maximum amount of a solid that can be dissolved in a liquid; e.g. magnesia into a slag, but applies to gases as well.

**Isothermal Section** – A diagram derived from a phase diagram that depicts the equilibria in the system at a designated temperature.

**Dual Saturation** – The maximum amount of two solids that can be in simultaneous equilibrium with a liquid.



**Figure 7.** Isothermal section from the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> at 1800°C highlighting the change in liquid chemistry (melt “m”) undergoes when exposed to various containment solids in the system. In effect, the saturation of the various solids in the liquid is defined where the path intersects the isotherm.

means that between 1600°C and 1400°C, not only did the chemistry reach a temperature where both mullite and tridymite were crystallizing simultaneously, the chemistry also reached the invariant eutectic temperature as well. It was at that temperature, 1440°C, that the third solid phase formed; that phase being cordierite. The final phase makeup for chemistry **y** is 36 wt% mullite, 11 wt% tridymite and 53 wt% cordierite.

Tracking the phase equilibria of a system using a series of isothermal sections is quite useful, as has been demonstrated in the previous discussion. However, the individual sections alone provide information on the saturation limit of liquids; particularly useful data for high temperature, molten liquid containment.

Considering the case of 1800°C, as shown in **Figure 7**, liquid saturation limits can be determined. The process begins by selecting a beginning liquid composition, point **m** in the figure. The ternary lever rule provides that the chemistry defined by point **m** is 11 wt% MgO, 40 wt% Al<sub>2</sub>O<sub>3</sub> and 49 wt% SiO<sub>2</sub>. The second step is selecting the particular solid of interest. In most refractory-related scenarios, the solid of interest would be established by the composition of the refractory being used to contain the liquid. In **Figure 7**, saturation of liquid with all of the solid compounds in the system is included for discussion purposes only so normally only one of the paths would be included. Take for instance, the case of containment of liquid **m** in a mullite crucible. Beginning at point **m**, a construction line can be drawn directly toward the mullite chemistry until it comes into

contact with the liquidus line. This line is effectively a tracking of the change in the liquid composition caused by corrosion and dissolution of the mullite. At the intersection of the liquids curve, the liquid is saturated (in equilibrium) with mullite, so no additional dissolution will occur; the liquid has reached the saturation limit at 1800°C. In this example, the composition of liquid has changed significantly, ending at 5 wt% MgO, 57 wt% Al<sub>2</sub>O<sub>3</sub> and 38 wt% SiO<sub>2</sub>. Similar logic can be used to consider each individual case of saturation of liquid **m** with alumina, spinel, magnesia, and forsterite using the construction lines included in **Figure 7**.

The situation can get slightly more complicated in cases where the liquid chemistry, on its way to becoming saturated in one solid, first becomes saturated in a different solid. This situation sounds unusual but is quite common. In those cases, the containment solid should now be considered as having its chemistry changed so that both solids are present. The liquid chemistry would then shift to the point where liquid and both solids are in equilibrium.

Consider a melt containing 90 wt% SiO<sub>2</sub> and 10 wt% Al<sub>2</sub>O<sub>3</sub> contained in a magnesia crucible. Magnesia will dissolve into the melt until the liquid composition reaches the liquidus line. In this case, the liquidus line indicates that the liquid is in equilibrium with the solid forsterite, not the containment solid, as had been the situation in all of the previous examples. At this point the liquid will react with magnesia to form forsterite and a

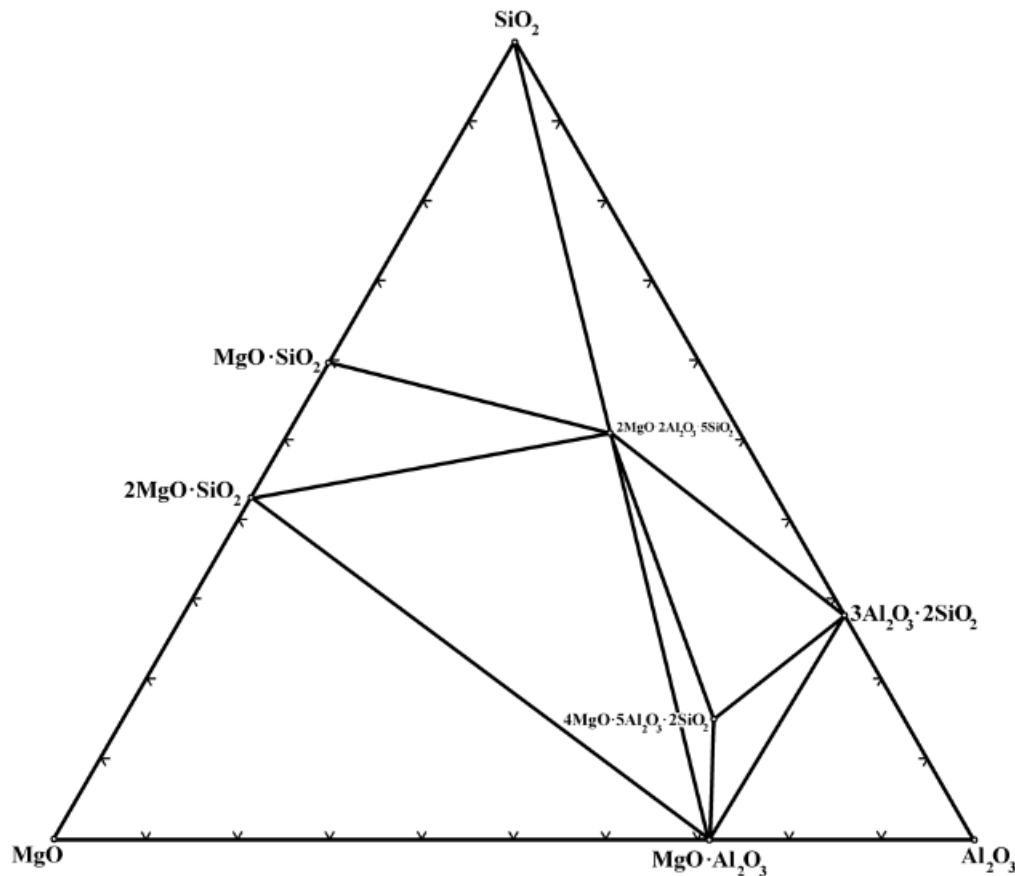


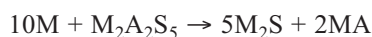
Figure 8. Isothermal section from the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system for temperatures below 1355°C.

different liquid. In this example there would be excess magnesia present so the final equilibrium would be between MgO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> and L<sub>a</sub>.

This case brings to light another common situation where more than one solid is being used to contain a liquid. The situation would be the same. Start with the liquid composition and construct a line directly toward the solid chemistry of interest, in such a case a mixture of two solids. Follow the liquid chemistry until it intersects a liquidus line and then follow it further until dual saturation of both solids is achieved.


The final aspect of isothermal sections is encountered when considering an isothermal section at temperatures below the lowest eutectic temperature in the system. For the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system the lowest eutectic temperature is 1355°C.

Constructing the isothermal section at say 1300°C, yields a diagram without liquid. In fact, only Alkemade lines would need to be included on the diagram. What results is a phase stability diagram, included as **Figure 8**. This diagram can be used to determine reactions that will occur in the system, as was described in great detail in a previous installment of *Phase Rules* [4]. As a quick example recall that the addition of magnesia to cordierite would cause a reaction to occur forming the components at the ends of whatever Alkemade line that is crossed. The actual reaction for this example would be as follows:



Isothermal sections are relatively easy diagrams to generate from an existing ternary phase diagram. These diagrams can be used, as described, to understand a host of high temperature processes, including liquid saturation, corrosion, sintering crystallization, etc., almost any solid/liquid interactions. The logical progression of the *Phase Rules* series is a manuscript on construction of vertical sections. That installment will be the most challenging to date, as the vertical sections are binary renderings of three-component equilibrium. They are quite useful but challenging to construct. Look for that manuscript in 2010.

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 Saint Louis, MO 63144  
 Tel: (314)963-7900  
 Fax: (314)963-7973  
 E-mail: [info@alsey.com](mailto:info@alsey.com)  
 Website: [www.alsey.com](http://www.alsey.com)



Aalsey Refractories Company specializes in the private branding of High Duty and Medium Duty Firebrick as well as wet and dry specialties for major manufacturers within the refractory industry.

Refractories Services Worldwide



**Dr. Charles E. Semler**  
 Refractories Consultant  
 10153 E. Elmwood Dr.  
 Chandler, AZ 85248  
 Tel: (480) 895-9830 Fax: (480) 895-9831  
 E-mail: [cesemler@aol.com](mailto:cesemler@aol.com)

Semler Materials Services provides varied services related to industrial refractories, based on 35 yrs. experience. Services include inspection/troubleshooting, failure analysis, product development, lining design review, standard/special testing, microscopy, sonic testing, sonic testing, quality assurance, corporate due diligence, workshops, legal/expert assistance, and more.

# Buyer's Guide Rates:

Suppliers please state which category you wish to be listed under or submit your own heading. Contact: Mary Lee, Missouri S&T, 223 McNutt Hall, Rolla, MO 65409, Tel: (573) 341-6561 Fax: (573) 341-6934, or E-mail: leemj@mst.edu. Rates for insertion: \$90 per listing in any category for 6 issues, one year. U.S. currency, **Payable in advance to: Refractories Applications and News.** Your company will also be listed on our website buyer's guide at no additional cost.

### ALUMINA-CALCINED

#### Almatis

501 West Park Rd., Leetsdale, PA 15056  
Tel: (412) 630-2800 Fax: (412) 630-2810  
www.almatis.com

#### AluChem, Inc.

One Landy Lane, Cincinnati, OH 45215  
Tel: (513) 733-8519 Fax: (513) 733-0608  
pormond@aluchem.com

#### NABALTEC AG

Alustraße 50 - 52, 92421 Schwandorf, Germany  
Tel: +49 9431 53-457 Fax: +49 9431 61557  
ceramics@nabaltec.de www.nabaltec.de

### ALUMINA-FUSED

#### C-E Minerals

901 East Eight Ave., King of Prussia, PA 19406  
Tel: (610) 768-8800 Fax: (610) 337-7163  
inquire@ceminerals.com www.ceminerals.com

#### Washington Mills Electro Minerals

PO Box 423, Niagara Falls, NY 14302-0423  
Tel: (800) 828-1666 Fax: (716) 278-6650  
sales@washingtonmills.com

### ALUMINA-REACTIVE

#### Almatis

501 West Park Rd., Leetsdale, PA 15056  
Tel: (412) 630-2800 Fax: (412) 630-2810  
www.almatis.com

#### AluChem, Inc.

One Landy Lane, Cincinnati, OH 45215  
Tel: (513) 733-8519 Fax: (513) 733-0608  
pormond@aluchem.com

#### NABALTEC AG

Alustraße 50 - 52, 92421 Schwandorf, Germany  
Tel: +49 9431 53-457 Fax: +49 9431 61557  
ceramics@nabaltec.de www.nabaltec.de

### ALUMINA-TABULAR

#### Almatis

501 West Park Rd., Leetsdale, PA 15056  
Tel: (412) 630-2800 Fax: (412) 630-2810  
www.almatis.com

#### AluChem, Inc.

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Tel: (513) 733-8519 Fax: (513) 733-0608  
pormond@aluchem.com

#### C-E Minerals

901 East Eight Ave., King of Prussia, PA 19406  
Tel: (610) 768-8800 Fax: (610) 337-7163  
inquire@ceminerals.com www.ceminerals.com

### ALUMINA-TRIHYDRATE

#### Almatis

501 West Park Rd., Leetsdale, PA 15056  
Tel: (412) 630-2800 Fax: (412) 630-2810  
www.almatis.com

### BASIC BRICKS

#### Resco Products, Inc.

Penn Center West, Bldg. 2, Ste. 430  
Pittsburgh, PA 15276  
Tel: (412) 494-4491 or (800) 354-1211  
Fax: (412) 494-4571  
sales@rescoproducts.com www.rescoproducts.com

### BAUXITE

#### C-E Minerals

901 East Eight Ave., King of Prussia, PA 19406  
Tel: (610) 768-8800 Fax: (610) 337-7163  
inquire@ceminerals.com  
www.ceminerals.com

#### Christy Minerals

833 Booneslick, High Hill, MO 63350  
Tel: (636) 585-2214 Fax: (636) 585-2220  
info@christyco.com www.christyco.com

#### Great Lakes Minerals, LLC

1200 Port Rd., Wurtland, KY 41144-1635  
Tel: (606) 833 8383 Fax: (606) 834 1106  
www.greatlakesminerals.com

### BORON CARBIDE

#### Electro Abrasives Corp.

701 Willet Rd., Buffalo, NY 14218  
Tel: (800) 284-4748 Fax: (716) 822-2858  
info@electroabrasives.com

#### Washington Mills Electro Minerals

PO Box 423, Niagara Falls, NY 14302-0423  
Tel: (800) 828-1666 Fax: (716) 278-6650  
sales@washingtonmills.com

### CALCIUM ALUMINATE CEMENT

#### Almatis

501 West Park Rd., Leetsdale, PA 15056  
Tel: (412) 630-2800 Fax: (412) 630-2810  
www.almatis.com

#### Kerneos Inc.

1316 Priority Lane, Chesapeake, VA 23324  
Tel: (757) 543-8832 Fax: (757) 545-8933  
www.kerneosinc.com www.secar.net.

#### USEM

600 Steel St., Aliquippa, PA 15001  
Tel: (724) 857-9880 Fax: (724) 857-9916  
lcurimbaba@usminerals.com

### CARBON

#### Cancarb Ltd.

1702 Brier Park Crescent N.W.  
Medicine Hat, Alberta, Canada T1C 1T8  
Tel: 1-(403) 527 1121 or 1-(888) 871-0077  
Fax: 1-(403) 529-6093  
Customer\_service@cancarb.com www.cancarb.com/

### CEMENT (AIR SETTING)

#### Resco Products, Inc.

Penn Center West, Bldg. 2, Ste. 430  
Pittsburgh, PA 15276  
Tel: (412) 494-4491 or (800) 354-1211  
Fax: (412) 494-4571  
sales@rescoproducts.com www.rescoproducts.com

### CERAMIC COATINGS

### SPECIALTY MOLD RELEASE AGENTS

#### UNIFRAX I LLC

2351 Whirlpool St., Niagara Falls, NY 14305  
Tel: (716) 278-3800 Fax: (716) 278-3900  
info@unifrax.com www.unifrax.com

### CERAMIC FIBER BOARDS

#### Refractory Specialties, Inc.

230 W. California Ave., Sebring, OH 44672  
Tel: (330) 938-2101 Fax: (330) 938-2574  
sales@rsifibre.com www.rsifibre.com

#### UNIFRAX I LLC

2351 Whirlpool St., Niagara Falls, NY 14305  
Tel: (716) 278-3800 Fax: (716) 278-3900  
info@unifrax.com www.unifrax.com

#### ZIRCAR Ceramics, Inc.

100 North Main St., P.O. Box 519  
Florida, NY 10921  
Tel: (845) 651-6600 Fax: (845) 651-0441  
dph@zircarceramics.com www.zircarceramics.com

### CERAMIC FIBER SHAPES

#### Refractory Specialties, Inc.

230 W. California Ave., Sebring, OH 44672  
Tel: (330) 938-2101 Fax: (330) 938-2574  
sales@rsifibre.com www.rsifibre.com

#### ZIRCAR Ceramics, Inc.

100 North Main St., P.O. Box 519  
Florida, NY 10921  
Tel: (845) 651-6600 Fax: (845) 651-0441  
dph@zircarceramics.com www.zircarceramics.com

### CHEMICAL ADDITIVES FOR THE REFRATORIES INDUSTRY

#### Zschimmer & Schwarz Inc

70 GA Highway 22 W, Milledgeville, GA 31061  
Tel 478 454 1942 Fax 478 453 8854  
PCuthbertZSUS@Windstream.Net  
www.Zschimmer-schwarz.com

### DRYING AND CURING OF REFRATORIES (ON SITE)

#### Excelsius Global Services GmbH

BGM, Dr Nebel Strasse 14  
97816, Lohr am Main Germany  
Tel: 0049 (0) 9352 604400  
Fax: 0049 (0) 9352 604419  
fschwarzenau@excelsius-lohr.de  
www.excelsius-global.com

#### Team Industrial Services

3640 W. 179th St., Hammond, IN 46323  
Tel: (219) 838-0505 Fax: (219) 838-8558  
cgorney@teamindustrialservices.com  
www.teamindustrialservices.com

### FIBERS - POLYPROPYLENE & GLASS

BassTech International  
300 Grand Ave., Englewood, NJ 07631  
Tel: (201) 569-8686 Fax: (201) 569-7511  
info@basstechintl.com www.basstechintl.com

### FIREBRICKS AND FIRECLAYS

#### C-E Minerals

901 East Eight Ave., King of Prussia, PA 19406  
Tel: (610) 768-8800 Fax: (610) 337-7163  
inquire@ceminerals.com www.ceminerals.com

#### Clayburn Refractories Ltd.

33765 Pine St., Abbotsford, BC, CA V2S 5C1  
Tel: 604-859-5288 or 604-851-4556  
rdlane@clayburngroup.com

# Buyer's Guide

## FIRECLAYS

### Christy Minerals

833 Booneslick, High Hill, MO 63350  
Tel: (636) 585-2214 Fax: (636) 585-2220  
info@christyco.com www.christyco.com

## FURNACE/REFRACTORY PREHEATING (ON SITE)

### Excelsius Global Services GmbH

BGM, Dr Nebel Strasse 14  
97816, Lohr am Main Germany  
Tel: 0049 (0) 9352 604400  
Fax: 0049 (0) 9352 604419  
fschwarzenau@excelsius-lohr.de  
www.excelsius-global.com

## FUSED ALUMINA

### C-E Minerals

901 East Eight Ave., King of Prussia, PA 19406  
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inquire@ceminerals.com www.ceminerals.com

### Great Lakes Minerals, LLC

1200 Port Rd., Wurtland, KY 41144-1635  
Tel: (606) 833 8383 Fax: (606) 834 1106  
www.greatlakesminerals.com

### USEM

600 Steel St., Aliquippa, PA 15001  
Tel: (724) 857-9880 Fax: (724) 857-9916  
lcuimbaba@usminerals.com

### Washington Mills Electro Minerals

PO Box 423, Niagara Falls, NY 14302-0423  
Tel: (800) 828-1666 Fax: (716) 278-6650  
sales@washingtonmills.com

## FUSED MULLITE

### C-E Minerals

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inquire@ceminerals.com www.ceminerals.com

### USEM

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Tel: (724) 857-9880 Fax: (724) 857-9916  
lcuimbaba@usminerals.com

### Washington Mills Electro Minerals

PO Box 423, Niagara Falls, NY 14302-0423  
Tel: (800) 828-1666 Fax: (716) 278-6650  
sales@washingtonmills.com

## FUSED SILICA

### C-E Minerals

901 East Eight Ave., King of Prussia, PA 19406  
Tel: (610) 768-8800 Fax: (610) 337-7163  
inquire@ceminerals.com www.ceminerals.com

### Minco, Inc.

510 Midway Circle, Midway, TN 37809  
Tel: (423) 422-6051 Fax: (423) 422-4802  
sales@mincoitc.com mincoitc.com

### Washington Mills Electro Minerals

PO Box 423, Niagara Falls, NY 14302-0423  
Tel: (800) 828-1666 Fax: (716) 278-6650  
sales@washingtonmills.com

## FUSED SPINEL

### C-E Minerals

901 East Eight Ave., King of Prussia, PA 19406  
Tel: (610) 768-8800 Fax: (610) 337-7163  
inquire@ceminerals.com www.ceminerals.com

### USEM

600 Steel St., Aliquippa, PA 15001  
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### Washington Mills Electro Minerals

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Tel: (800) 828-1666 Fax: (716) 278-6650  
sales@washingtonmills.com

## HIGH ALUMINA FIREBRICKS

### Clayburn Refractories Ltd.

33765 Pine St., Abbotsford, BC, CA V2S 5C1  
Tel: 604-859-5288 or 604-851-4556  
rdlane@clayburngroup.com

### Resco Products, Inc.

Penn Center West, Bldg. 2, Ste. 430  
Pittsburgh, PA 15276  
Tel: (412) 494-4491 or (800) 354-1211  
Fax: (412) 494-4571  
sales@rescoproducts.com  
www.rescoproducts.com

### Saint-Gobain Ceramics

1 New Bond St., MS 301-432,  
Worcester, MA 01615-0136  
Tel: (508) 795-2963 Fax: (508) 795-5011  
patrick.m.stephan@saint-gobain.com  
www.refractories.saint-gobain.com

### Sunrock Ceramics Company

2625 S. 21st Ave., Broadview, IL 60155  
Tel: (708) 344-7600, Fax: (708) 344-7636  
dthurman@sunrockceramics.com  
www.sunrockceramics.com

## HIGH PURITY MAGNESITE

### AluChem, Inc.

One Landy Lane, Cincinnati, OH 45215  
Tel: (513) 733-8519 Fax: (513) 733-0608  
pormond@aluchem.com

## INSULATING BRICKS

### Clayburn Refractories Ltd.

33765 Pine St., Abbotsford, BC, CA V2S 5C1  
Tel: 604-859-5288 or 604-851-4556  
rdlane@clayburngroup.com

### IFB, Inc.

610 East Butler Rd., Butler, PA 16002  
Tel: (724) 282-1012 Fax: (724) 285-7673  
ifbine@aol.com  
www.insulatingfirebrick.com

### Saint-Gobain Ceramics

1 New Bond St., MS 301-432  
Worcester, MA 01615-0136  
Tel: (508) 795-2963 Fax: (508) 795-5011  
patrick.m.stephan@saint-gobain.com  
www.refractories.saint-gobain.com

## KILN/FURNACE FURNITURE

### Applied Ceramics, Inc.

5555 Pleasantdale Rd., Atlanta, GA 30340  
Tel (678) 735-4925 Fax (770) 368-8261  
Sean.McDevitt@AppliedCeramics.com  
www.appliedceramics.com

### N<sup>th</sup> Degree Products

404 Laurel Ridge Rd., Hainesport, NJ 08036  
Tel: (609) 518-9447 Fax: (609) 518-9445  
nthdegreeproducts@Yahoo.com

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1 New Bond St., MS 301-432  
Worcester, MA 01615-0136  
Tel: (508) 795-2963 Fax: (508) 795-5011  
patrick.m.stephan@saint-gobain.com  
www.refractories.saint-gobain.com

### Sunrock Ceramics Company

2625 S. 21st Ave., Broadview, IL 60155  
Tel: (708) 344-7600, Fax: (708) 344-7636  
dthurman@sunrockceramics.com  
www.sunrockceramics.com

## KYANITE

### Kyanite Mining Corporation

Dillwyn VA 23936  
Tel Sales: (434) 983-2043  
info@kyanite.com www.Kyanite.com

## MONOLITHIC FIBER GUNNING

### UNIFRAX I LLC

2351 Whirlpool St., Niagara Falls, NY 14305  
Tel: (716) 278-3800 Fax: (716) 278-3900  
info@unifrax.com www.unifrax.com

## MONOLITHIC PUMPABLE

### UNIFRAX I LLC

2351 Whirlpool St., Niagara Falls, NY 14305  
Tel: (716) 278-3800 Fax: (716) 278-3900  
info@unifrax.com www.unifrax.com

## MONOLITHIC REFRACTORIES

### ARTECH TECHNOLOGIES LLC -

### ACTCHEM@ USA

1000 S. Elmwood, P.O. Box 754, Mexico, MO 65265  
Tel: (800)708-9470  
info@actchem-usa.com

### XERTECH SPECIALTIES LLC

1000 S. Elmwood, P.O. Box 754, Mexico, MO 65265  
Tel: (330)770-7714 Fax:(330)629-9252  
info@xertechllc.com

## MONOLITHIC REFRACTORIES-CASTABLE

### Clayburn Refractories Ltd.

33765 Pine St., Abbotsford, BC, CA V2S 5C1  
Tel: 604-859-5288 or 604-851-4556  
rdlane@clayburngroup.com

### High-Temp, Inc.

14025 N. Rivergate Blvd., Portland, OR 97203  
Tel: 1 (800) 325-2492 Fax: (503) 737-0771  
lesg@hightempinc.net www.hightempinc.net

### Resco Products, Inc.

Penn Center West, Bldg. 2, Ste. 430  
Pittsburgh, PA 15276  
Tel: (412) 494-4491 or (800) 354-1211  
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sales@rescoproducts.com www.rescoproducts.com

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1 New Bond St., MS 301-432  
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patrick.m.stephan@saint-gobain.com  
www.refractories.saint-gobain.com

## MONOLITHIC REFRACTORIES GUNNING

### Clayburn Refractories Ltd.

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## MONOLITHIC REFRACTORIES PUMPABLE

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sales@rescoproducts.com www.rescoproducts.com

## MONOLITHIC REFRACTORIES MOULDABLE

### Resco Products, Inc.

Penn Center West, Bldg. 2, Ste. 430  
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Tel: (412) 494-4491 or (800) 354-1211  
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# Buyer's Guide

## MULLITE

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info@kyanite.com www.Kyanite.com

**NABALTEC AG**  
Alustraße 50 - 52, 92421 Schwandorf, Germany  
Tel: +49 9431 53-457 Fax: +49 9431 61557  
ceramics@nabaltec.de www.nabaltec.de

## OLIVINE

**Minelco Inc.**  
2020 Scripps Ctr., 312 Walnut St.  
Cincinnati, OH 45202  
minelco.inc@minelco.com www.minelco.com

**Unimin Corporation**  
258 Elm St., New Canaan, CT 06840  
Tel: 800-243-9004 Fax: 800-243-9005  
metalcaster@unimin.com www.metalcaster.com

## PHOSPHATE BINDERS & DEFLOCCULANTS

**BassTech International**  
300 Grand Ave., Englewood, NJ 07631  
Tel: (201) 569-8686 Fax: (201) 569-7511  
info@basstechintl.com www.basstechintl.com

## PRE-CAST REFRACTORY SHAPES

**High-Temp, Inc.**  
14025 N. Rivergate Blvd., Portland, OR 97203  
Tel: 1 (800) 325-2492 Fax: (503) 737-0771  
lesg@hightempinc.net www.hightempinc.net

**TFL, Incorporated**  
14626 Chrisman, Houston, TX 77039  
Tel: 281-590-8500 or 800-828-5002  
Fax: 281-590-5342  
tfl@tflhouston.com www.TFLHouston.com

**ZIRCAR Ceramics, Inc.**  
100 North Main St., P.O. Box 519  
Florida, NY 10921  
Tel: (845) 651-6600 Fax: (845) 651-0441  
dph@zircarceramics.com www.zircarceramics.com

## PRECISION REFRACTORY SHAPES

**Resco Products, Inc.**  
Penn Center West, Bldg 2, Ste. 430  
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Tel: (412) 494-4491 or (800) 354-1211  
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**Saint-Gobain Ceramics**  
1 New Bond St., MS 301-432  
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Tel: (508) 795-2963 Fax: (508) 795-5011  
patrick.m.stephan@saint-gobain.com  
www.refractories.saint-gobain.com

## PRESS TOOLING

**JLW Ventures, Inc., D/B/A Johnson Machine Co.**  
P.O. Box 669, 290 Bigler Ave., Clearfield, PA 16830  
Tel: (814) 765-9648 Fax: (814) 765-9640  
inquiry@johnsonmachineco.com  
www.johnsonmachineco.com

**Alcon Tool Company**  
587 Baird St., Akron, OH 44311  
Tel: 330-773-9171 Fax 330-773-8042  
www.alcontool.com rd@alcontool.com

## PRODUCT ENGINEERING/QA SERVICES

**VanceCeramics101, Inc.**  
23 Pheasant Run Dr., Expt PA 15632  
Tel: or Fax: (724) 327-1680  
bvance23@comcast.net

## REFRACTORY AGGREGATES

**C-E Minerals**  
901 East Eight Ave., King of Prussia, PA 19406  
Tel: (610) 768-8800 Fax: (610) 337-7163  
inquire@ceminerals.com www.ceminerals.com

**Resco Products, Inc.**  
Penn Center West, Bldg. 2, Ste. 430  
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Tel: (412) 494-4491 or (800) 354-1211  
Fax: (412) 494-4571  
sales@rescoproducts.com  
www.rescoproducts.com

**Unimin Corporation**  
258 Elm St., New Canaan, CT 06840  
Tel: 800-243-9004 Fax: 800-243-9005  
metalcaster@unimin.com www.metalcaster.com

## REFRACTORY ANCHORS

**Resco Products, Inc.**  
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## REFRACTORY CERAMIC FIBER

**UNIFRAX I LLC**  
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info@unifrax.com www.unifrax.com

## REFRACTORY BRICKWORK INSTALLATIONS

**Clayburn Refractories Ltd.**  
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Tel: 604-859-5288 or 604-851-4556  
rdlane@clayburngroup.com

## REFRACTORY GUNNING INSTALLATIONS

**Clayburn Refractories Ltd.**  
33765 Pine St., Abbotsford, BC, CA V2S 5C1  
Tel: 604-859-5288 or 604-851-4556  
rdlane@clayburngroup.com

## REFRACTORY GUNNING & SHOTCRETE EQUIPMENT

**Blastcrete Equipment Company**  
2505 Alexandria Rd., PO Box 1964  
Anniston, AL 36202  
Tel: (256) 235-2700 or 1 (800) 235-4867  
Fax: (256) 236-9824  
jim@blastcrete.com or tripp@blastcrete.com

## REFRACTORY LANCES

**High-Temp, Inc.**  
14025 N. Rivergate Blvd., Portland, OR 97203  
Tel: 1 (800) 325-2492 Fax: (503) 737-0771  
lesg@hightempinc.net www.hightempinc.net

## REFRACTORY MACHINING

**Refractory Machining Services**  
610 E. Butler Rd., Butler, PA 16002  
Tel: (724) 285-7674 Fax: (724) 285-7673  
refrmachserv@aol.com

## REFRACTORY RECYCLING

**A-TEN-C, Inc.**  
P.O. Box 58184, Pittsburgh, PA 15209  
Tel: (412) 821-5566 Fax: (412) 821-5577  
atencinci@verizon.net www.ceramicrecycling.com

**J. H. Mac, Inc.**  
610 East Butler Rd., Butler, PA 16002  
Tel: (724) 285-7222 Fax: (724) 431-0944  
Sales@JHMacinc.com www.JHMacinc.com

## REFRACTORY MIXERS

**RFI Construction Products**  
Division of Cangro Industries, Inc.  
495 Smith St., Farmingdale, NY 11735-1186  
Tel: (631) 752-8899 Fax: (631) 454-9155  
cangrosales@ix.netcom.com  
www.rficonstructionproducts.com/

Lancaster Products, Div. of Kercher Industries, Inc.  
920 Mechanic St., Lebanon, PA 17046  
Tel: (717) 273-2111, (800) 447-7351  
info@lancasterprpd.com www.lancasterprpd.com

## REFRACTORY RAW MATERIALS

**Unimin Corporation**  
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Tel: 800-243-9004 Fax: 800-243-9005  
metalcaster@unimin.com www.metalcaster.com

## REFRACTORY SHOTCRETE INSTALLATIONS

**Clayburn Refractories Ltd.**  
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Tel: 604-859-5288 or 604-851-4556  
rdlane@clayburngroup.com

## SILICA BRICK

**Utah Refractories Corp.**  
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tlmpgh@aol.com

## SILICA MATERIALS

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metalcaster@unimin.com www.metalcaster.com

## SILICON CARBIDE

**Electro Abrasives Corp.**  
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info@electroabrasives.com

**International Minerals, Inc.**  
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Tel: (724) 857-9903 Fax: (724) 857-9917  
jk@imi-minerals.com www.imi-minerals.com

**Washington Mills Electro Minerals**  
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Tel: (800) 828-1666 Fax: (716) 278-6650  
sales@washingtonmills.com

## SILICON CARBIDE REFRACTORY SHAPES

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Worcester, MA 01615-0136  
Tel: (508) 795-2963 Fax: (508) 795-5011  
patrick.m.stephan@saint-gobain.com  
www.refractories.saint-gobain.com

## SILICON METAL POWDER

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info@basstechintl.com www.basstechintl.com

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www.almatis.com

## STEEL FIBERS

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info@fiberconfiber.com www.fiberconfiber.com

## TITANIA

**Sachtleben Chemical Company**  
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Tel: (614) 284-9699 Fax: (614) 761-7909  
vrestivo@hotmail.com www.sachtleben.com

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### TOLL CRUSHING & GRINDING

#### AluChem, Inc.

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Tel: (513) 733-8519 Fax: (513) 733-0608  
pormond@aluchem.com

#### Christy Minerals

833 Booneslick, High Hill, MO 63350  
Tel: (636) 585-2214 Fax: (636) 585-2220  
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### TOLL PROCESSING

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### VACUUM FORM SHAPES

#### Refractory Specialties, Inc.

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sales@rsifibre.com www.rsifibre.com

#### ZIRCAR Ceramics, Inc.

100 North Main St., P.O. Box 519  
Florida, NY 10921  
Tel: (845) 651-6600 Fax: (845) 651-0441  
dph@zircarceramics.com www.zircarceramics.com

### ZIRCON SAND & FLOUR

#### AluChem, Inc.

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