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Refractories Applications and News

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Join Theodore J. Planje Award recipients and meet the incoming member of this select group at the 45th St. Louis Refractories Symposium

From left to right, Louis J. Trostel, 1996, Orville Hunter Jr., 1998, Kent Weisenstein, 2000, Richard C. Bradt, 1988, Howard Johnson, 2008, Dilip Jain, 2003, Charles E. Semler, 1995, Mark A. Stett, 2001, George Taylor, 2005. Leonard Krietz, 2007.

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From the Editor . . .

Jeffrey D. Smith, Editor, *jsmith@mst.edu*

Jeffrey D. Smith

Another St. Louis Refractory meeting is upon us. The meeting has become the most important annual meeting of the refractory community in North America. The agenda is quite full as always with a strong technical content and ample opportunity to socialize and conduct business. Come join in, I think you will enjoy it.

This issue of RAN is quite full having considerable contribution in the standard part and includes a Transactions contribution by James Hemrick entitled "Non-Classical Creep Behavior of Fusion-Cast α/β Alumina Refractories". The latest addition of *Phase Rules* is also in this issue. These installments continue to increase in complexity and I need to again thank Todd Sander for his efforts related to creating tables and figures. It is a bit shocking to see the amount of effort that is necessary to produce the detail that is required for manuscripts of this type.

A last note concerns the figure that is included at the end of this editorial. During the last bit of editing and shifting things around in the issue, this figure was removed. We apologize for any inconvenience this omission may have caused. RAN

Correction

Figure 4 was missing in the January/February 2009 article "Polymer Bonded Refractories" by D. Martin and O. Hunter, Jr.

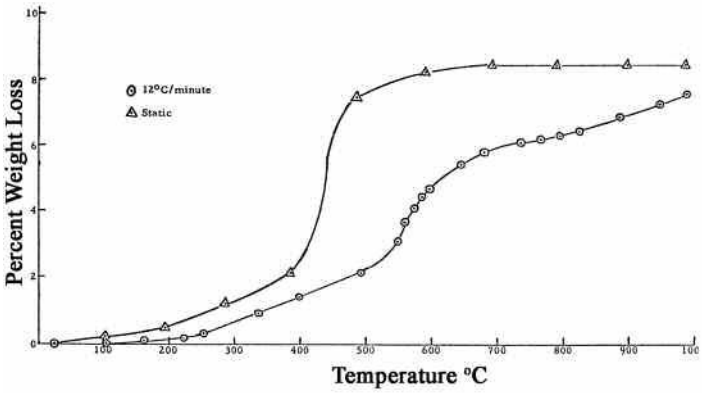

Figure 4. Percent weight loss as a function of temperature for silicone-alumina compact. (Image from "Polymer Bonded Refractories", figure was missing in the Jan/Feb 2009 issue.

CONTENTS

Refractories Applications *and News*

Refractories Applications *Transactions*

ADVERTISING INDEX

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REFRACTORIES RELATED MEETINGS

2009

March 25-26, **St. Louis Section and the Refractory Ceramics Division 45th Annual Symposium**, Hilton St. Louis Airport Hotel, St. Louis, MO.

April 5-8, **5th International Materials Symposium (MATERIALS 2009**), Lisbon, Portugal, The conference addresses all classes of materials, focusing on the latest advances in theory, modeling, simulation, characterization, processing, and industrial applications. The following topics are especially welcome for presentation in MATERIAlS 2009: effects only present at the nanoscale; molecularly engineered materials; crystallography, defects associated with crystal structures, and their relation to physical properties; high temperature materials; materials for civil engineering applications; fabrication of devices using electronic and electro-optic materials, and others. Visit the web site for complete listing of topics. Contact: Carlos Anjinho, Instituto Superior Tecnico, Dept. of Materials Engineering, av. Rovisco Pais, Lisbon 1049-001, Portugal. Phone: +351-218-418-135, E-mail: materiais2009@ist.utl.pt.

April 16-17, **4th Global Foundry Sourcing Conference 2009**, Shanghai, P.R. China, Contact: Annabelle Chen, Suppliers China Information Consultation Co., Ltd., Room 2608, Bldf 3, 41 Jilin Road, Qingdao 266012, China, Tel: +86-532-8586-0799, E-mail: princessfrog@foundry-suppliers.cn.

Apr. 20-23, **5th International Ceramic Interconnect and Ceramic Microsystems Technologies Conference - CICMT 2009**, Curtis Hotel, Denver, CO.

May 4–7, **AISTech 2009 - The Iron & Steel Technology Conference and Exposition**, America's Center in St. Louis, MO. Abstracts for this major international conference are being sought now for manuscripts to be presented at the event and published in the proceedings. Featuring international technologies from the world over, allowing steel producers to compete in today's global market. If you are involved in the steel industry, you can't afford to miss this event. Whether you present, attend or exhibit, take advantage of this opportunity to discover ways to make your job easier and improve your productivity.

May 31-June 5, **8th Pacific Rim Conference on Ceramic and Glass Technology - PACRIM 8**, Includes **2009 Annual Meeting of the International Commission on Glass (ICG)**, Hyatt Regency Vancouver, Vancouver, BC, CA.

August 29-September 2, **The 30th International Thermal Conductivity Conference and the 18th International Thermal Expansion Symposium,** Seven Springs Mountain Resort near Pittsburgh, PA. The conference will be hosted by Anter Corporation (Pittsburgh, PA, USA) and the University of Lisbon (Portugal), www.thermalconductivity.org.

September 23-24, **52nd International Colloquium on Refractories 2009**, Aachen, Eurogress, Germany, Forschungsgemeinschaft Feuerfest e.V. – Feuerfest-Kolloquium – An der Elisabethkirche 27 · 53113 Bonn, Germany, Tel:+49-(0)228-91508-45, Fax:+49-(0)228-91508-55, E-Mail: info@feuerfest-kolloquium.de, www.feuerfest-kolloquium.de.

October 13-16, **UNITECR 2009 - 11th Biennial Worldwide Conference on Refractories**, Pestana Bahia Hotel, Salvador, Brazil, www.unitecr2009.org/.

October 25-30, **Materials Science & Technology 2009 Conference and Exhibition - MS&T '09** combined with the **ACerS 111th Annual Meeting**, David L. Lawrence Convention Center, Pittsburgh, PA.

2010

January 24-29, **34th 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.

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

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

Send meeting announcements to Mary Lee at: leemj@mst.edu
Announcements must be received a minimum of four months prior to the meeting date.

Rob Crolius

Planning for UNITECR 2009

It is not too early to plan to attend the upcoming Unified International Technical Conference on Refractories (UNITECR) to be held at the Pestana Bahia Hotel in Salvador, Brazil, October 13-16, 2009.

The theme of the conference is "Refractories in a Shifting Globalized World". Technical Program Chair Dr. Geraldo Eduardo Gonçalves of Magnesita Refratarios reports that the committee has received 244 abstracts. Topics include refractories for iron and steel, nonferrous metallurgy, cement and lime, glass and petrochemical, as well as recycling, nanoengineered refractories, characterization, modeling, installation, raw materials, and education. There will also be a short course on thermal shock resistance of engineered microstructure.

Salvador, Brazil is a city that blends the modern with the historical. Founded in 1549, the city features a picturesque colonial quarter surrounded by 21st Century Brazil. Its position on a peninsula on Brazil's coast 13º south of the equator provides a warm but not oppressive climate. The average temperature is about 77ºF.

Air access from North America is usually through Rio de Janeiro and São Paulo, although there have been direct flights from Miami and New York to Salvador in the past.

One important note. Citizens of the United States are required to have a visa for entry into Brazil. This requirement is based on the fact that the U.S. requires Brazilians to obtain visas prior to entry into the U.S.

Brazilian visa applications must be filed with the appropriate Brazilian consulate office based on the state of residence of the applicant. For example, Pennsylvania residents must apply for visas in the New York City office, Connecticut residents in Boston.

The easiest way to apply is to use a visa service. Once you have your flight information, you can complete and download a visa application on the internet. Then you can send the completed application and a copy of your plane ticket, with appropriate documentation and waivers, with checks for the visa fee and the visa service, plus your passport, to the appropriate service for processing. Allow at least three or four weeks for normal service, although for a premium you usually can get expedited service.

The important point to remember is to begin the application process early and become familiar with all application requirements and steps prior to beginning the process to ensure a timely and hassle-free visa application process. Brazilian visas are good for a year.

Obama Administration Takes Hold of Regulatory Process

On day one of the Obama Administration, Rham Emanuel, President Obama's chief of staff issued a memorandum directing federal agencies and departments to:

- not send proposed or final rules to the Office of Management and Budget (OMB) until they were approved by an agency head appointed by President Obama;
- withdraw all Bush Administration Federal Register notices (proposed and final) at the Office of the Federal Register that had not yet been published;
- consider extending by 60 days the effective date of all rules that have already been published in the Federal Register but have not yet taken effect; and
- consider reopening the notice and comment period for 30 days for any rules that had not taken effect.

There are some exceptions to these directions, mostly pertaining to rules subject to judicial or statutory deadlines. The practical impact of this memorandum is the delay in the issuance or effective date of essentially all federal regulations that were in development prior to the new president taking office.

Congress, President Move on Labor Legislation

While the economic recovery and confirmation of Obama appointees takes the spotlight, the Congress is moving forward with legislation which was stymied in the previous administration.

In one of its first actions, Congress passed and President Obama signed the Ledbetter Fair Pay Act which extends substantially the statute of limitations under civil rights laws for bringing suits against employers over pay discrimination. In addition, action is expected soon in Congress on the Paycheck Fairness Act (H.R. 12) which expands damages under the Equal Pay Act of 1963 for women who are not paid equal wages as compared to their male counterparts.

The quick action on these bills had been expected as Democratic legislators had campaigned for their passage. The business community has opposed them, fearing they could lead to frivolous lawsuits.

Waxman Promises Action on Climate Change and Energy

House Energy and Commerce Committee Chairman Henry Waxman has vowed to move comprehensive climate and energy legislation out of his committee prior to Memorial Day in a bid to give President Obama a major environmental achievement in his first term. While few details are yet available, the legislation is expected to build off of previous cap and trade proposals as well as recommendations made by the U.S. Climate Action Partnership.

Electro Abrasives Joins with U.S. Electrofused Minerals/ELFUSA

The Electro Abrasives Corporation has announced that the company has signed a purchase agreement with U.S. Electrofused Minerals Inc./ELFUSA effective at the end of 2008.

Electro Abrasives will now become Electro Abrasives, LLC. Electro Abrasives manufactures black silicon carbide, green silicon carbide, and boron carbide. U.S. Electrofused Minerals/ Elfusa is a producer of abrasives involved in the mining and fusing of abrasive and refractory materials. RAN

DEMAND FOR CEMENT IN CHINA TO APPROACH 1.8 BILLION METRIC TONS IN 2012

Demand for cement in China is forecast to rise 6.0 percent annually through 2012 to 1.8 billion metric tons. Growth will be driven by rising, but decelerating, construction expenditures in China. Further advances in cement manufacturing technology will also help stimulate sales by improving the quality of the product. Blended cements will account for about 90 percent of total sales in 2012, reflecting the versatility of these types across a range of construction applications, as well as their performance and/or price benefits over competitive cements. These and other trends are presented in Cement in China, a new study from The Freedonia Group, Inc., a Cleveland-based industry research firm.

Nonresidential building construction will continue to represent the largest end use for cement, benefiting from ongoing industrialization in China. Nonresidential building cement consumption will also be boosted by the construction of new manufacturing facilities as the Chinese industrial sector focuses on more value added goods. However, demand for cement in nonbuilding construction will outpace other construction categories, rising 7.3 percent annually to 544 million metric tons in 2012. In the short term, demand for cement used in infrastructure applications will benefit from government spending packages designed to offset the effects of the global economic downturn. In the longer term, a number of large infrastructure projects and other government initiatives to address imbalances in development between urban and rural areas will boost nonbuilding cement consumption.

For more information contact, Corinne Gangloff, Media Relations, Tel: +1 440.684.9600, Fax: +1 440.646.0484 or pr@freedoniagroup.com.

US CEMENT DEMAND IN CHINA (million dollars)

Item	2002	2007	2012	% Annual Growth 2002- 2007	% Annual Growth 2007-2012
Cement Demand	721	1335	1790	13.1	6.0
Construction Contractors	270	454	569	11.0	4.6
Concrete Products	226	395	513	11.8	5.4
Ready-Mix Concrete	79	240	383	24.9	9.8
Consumers	64	123	167	14.0	6.3
Other	82	123	158	8.4	5.1

BRAULIO AWARDED 2008 WAKABAYASHI PRIZE

The Technical Association of Refractories of Japan, will award the 2008 Wakabayashi Prize to Mariana Braulio, for the best paper published in the Journal of the Technical Association of Refractories, named "Microsilica Effects on Cement Bonded Alumina-Magnesia Refractory Castables" (Vol. 28, No.3, pp.180-184), at its general meeting on April 20th 2009, in Sendai, Japan. Her contribution was co-authored by L. Bittencourt, J. Poirier and V. C. Pandolfelli. The Wakabayashi Prize, named by the founder of the association, has been awarded since 1983 in order to promote and keep a high scientific publication level in the refractory area.

This research work is part of a broader research project, funded by FIRE, an association founded by industrial and academic partners in the refractory field (www.fire.polymtl.ca), and is directed by Professor Victor Pandolfelli, from University Federal of São Carlos, in Brazil. New significant results on this subject will be presented at the UNITECR'09 meeting, in Salvador, Brazil, next October (13 to 16, 2009), as well as on the other projects sponsored by FIRE.

CHINA CERAMIC DIRECTORY JUST PUBLISHED

Business Data International Inc., the business and professional information provider, has recently announced that the only English-language China Ceramic Directory 2008 has just been published. The 321-page directory is a comprehensive and up-to-date information source on the Chinese ceramic industry. The directory provides a list of about 1,300 leading ceramic and pottery enterprises, research institutes, associations, importers and exporters in China. It covers commonly used ceramics, porcelain products, sanitaryware, building ceramics, tile, electroceramics, refractories, technical and industrial ceramics, ceramic raw materials, equipment and machines, as well as publications. The directory provides information on each organization's name, address, telephone and fax numbers, e-mail addresses and websites, name of the director, registered capital, number of employees, history, production capacity and main products.

Further information on ordering is available from Business Data International Inc., info@businessdataintl.com or Fax: +1 (514) 227-5424, www.businessdataintl.com.

SWECO OPENS NEW AIR CLASSIFIER TEST FACILITY

Sweco, A Business Unit of M-I L.L.C., is proud to announce the opening of a new North American test facility for its Ecutec business unit. Located in Florence, Kentucky the 1000 square foot laboratory will be used to conduct milling, classification and coating trials on fine and ultrafine particles.

This new Ecutec lab is capable of milling and classifying products as fine as 1 mm. With a capacity of up to 1800 kg/hr (2 TPH) the lab will be available for both small scale batch tests as well as pilot scale toll processing. It includes an 8000 RPM Ecutec NEA50 air classifier and a 22 kW (30 HP) KGM ball mill. In-line instrumentation continuously monitors and logs measurements of speed, temperature, pressure, flow and particle size parameters. Additionally, a custom designed control panel with a web interface allows for remote monitoring and control.

There are now four Ecutec pilot scale test facilities around the world. Other locations include Barcelona, Spain; Enns, Austria; and Kolkata, India. The new Florence lab is part of a project to build 3000 square feet of new laboratory and analytical space to support Sweco's North American industrial business.

Sweco serves the pharmaceutical, chemical, food, minerals, paper and many other industries with a complete line of separation, sizing and milling equipment. For more information, please visit www.sweco.com or e-mail info@sweco.com. RAN

PHASE EQUILIBRIA DIAGRAMS OF THREE COMPONENTS - REACTIONS AND CRYSTALLIZATION

Jeffrey D. Smith, Associate Professor, Department of Materials Science and Engineering, Missouri University of Science and Technology, *jsmith@mst.edu*

In the last installment of *Phase Rules* [1] considerable time was devoted to the relationship between two and three component systems. One of the critical aspects of true binary systems was that they were required to lie upon an alkemade line. These alkemade lines are significant in other ways, and the issues associated with them will be addressed first in this installment. A rendering of the magnesia-alumina-silica (MAS) diagram is included as **Figure 1**.

Alkemade lines are significant to phase equilibria, even in the absence of all the other information related to the system. In instances where such lines are absent they can be added based upon the principle that two compounds whose phase fields touch must have an alkemade line between them. Of course, the complication with this relates to the fact that compounds, and their associated phase fields, can appear and disappear as a function of tem-

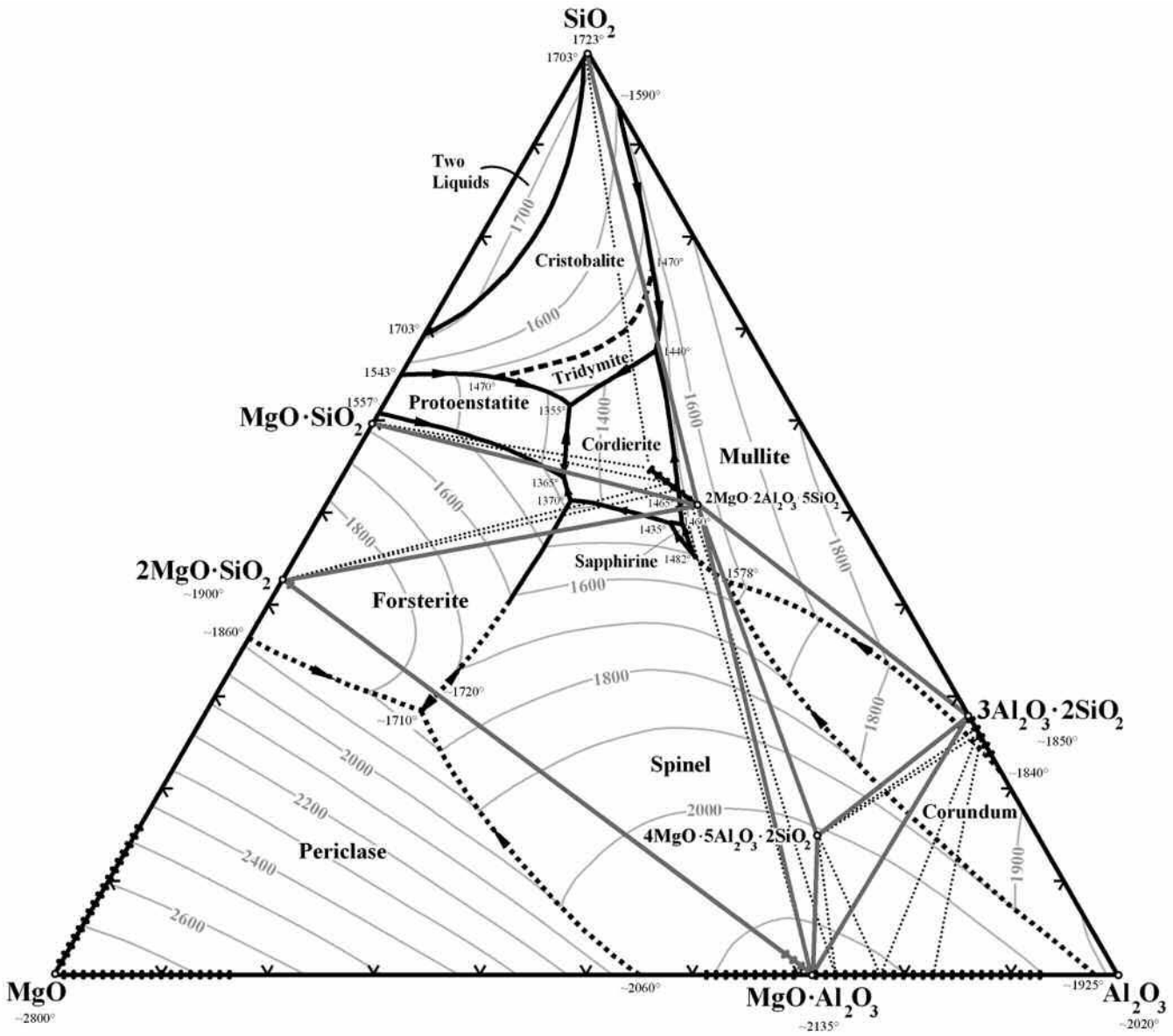

Figure 1. Ternary phase diagram representing the MgO-Al_2O_3-SiO_2 system [1].

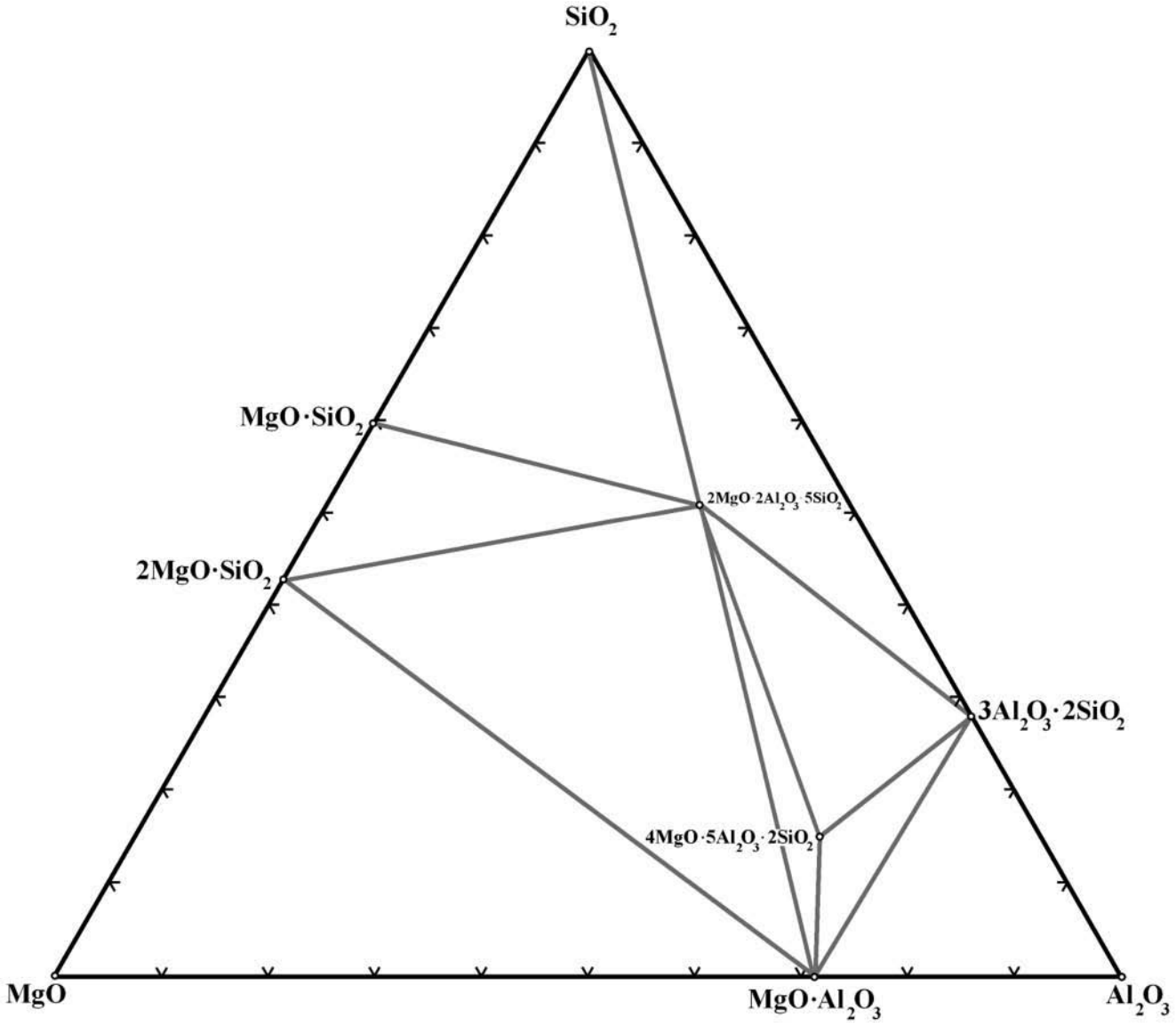

Figure 2. Ternary phase compatibility diagram of the MgO-Al_2O_3-SiO_2 system showing alkemades without considering solid solution.

perature. For example, a compound that forms on cooling via a peritectoid reaction and then dissociates via a eutectoid reaction at a slightly lower temperature would only have alkemade lines during those few degrees where the phase is stable.

The issue of stability is key as alkemade lines "connect" stable phases. Ignoring the solid solution complication for a moment, one can connect all the compounds with adjacent phase fields. Once completed, a record of the phase stability in the system exists. This is extremely important, as an engineer or scientist now knows what equilibrium reactions should occur in the system. **Figure 2** shows the MAS system with the alkemade lines.

Determining what reaction might occur between any two compounds is a simple matter of drawing a construction line between them. There are only three possibilities: (1) the construction line will lie on an alkemade line; (2) the construction line will lie on two or more alkemade lines; or (3) the construction line will cross an alkemade line or lines.

In situations where the construction line is coincident with an alkemade line, no reaction occurs; the two compounds are stable. Heating a mixture of these two compounds will not change the equilibrium. A number of binary mixtures in the MAS system will result in no reaction and a complete list is included as **Table 1**.

In order to simplify the process of indicating reactions in the MAS system a special notation will be utilized. The notation is

Table 1. Stable binary mixtures in the system

Stable Binary Mixtures	
Cristobalite	Mullite
Cristobalite	Cordierite
Cristobalite	Protoenstatite
Protoenstatite	Cordierite
Protoenstatite	Forsterite
Forsterite	Cordierite
Forsterite	Spinel
Forsterite	Periclase
Periclase	Spinel

Stable Binary Mixtures	
Spinel	Cordierite
Spinel	Sapphirine
Spinel	Mullite
Spinel	Corundum
Corundum	Mullite
Mullite	Sapphirine
Mullite	Cordierite
Sapphirine	Cordierite

based on cement notation whereby the main oxides magnesia, alumina and silica are indicated as M, A, and S respectively. Additionally the number of molecules is indicated by a subscript number following the letter. For example, $2MgO•SiO_2$ is indicated as M_2S. The oxides in the MAS system and their corresponding cement notation are included as **Table 2**.

In situations where the construction line lies on more than one alkemade line, the two components will react to form the new compound.

Table 2. Simplified oxide notation compounds in the MAS system

Notation		
Name	**Chemical**	**Cement**
Cristobalite	SiO_2	S
Protoenstatite	$MgO·SiO_2$	MS
Forsterite	$2MgO·SiO_2$	M_2S
Periclase	MgO	M
Spinel	$MgO·Al_2O_3$	MA
Cordierite	$2MgO·2Al_2O_3·5SiO_2$	$M_2A_2S_5$
Sapphirine	$4MgO·5Al_2O_3·2SiO_2$	$M_4A_5S_2$
Corundum	Al_2O_3	A
Mullite	$3Al_2O_3·2SiO_2$	A_3S_2

For instance, a mixture of MgO and Al_2O_3 results in a construction line that rests on both the MgO - $MgAl_2O_4$ and $MgAl_2O_4$ - Al_2O_3 alkemades. Therefore, that mixture will result in spinel formation by the following reaction:

$$MgO_{(s)} + Al_2O_{3(s)} \rightarrow MgAl_2O_{4(s)}$$

Mixtures other than the stoichiometric 1:1 molar MgO:Al_2O_3 will result in some amount of MgO or Al_2O_3. In those instances the resulting binary mixture of spinel with either periclase or corundum is stable as they are connected by an alkemade line. **Table 3** shows shows the other reactions in the system that are similar.

Table 3. Binary reactions in the MAS system

Binary Reactants	Stoichiometric Reactions
Periclase + Corundum	$M + A \rightarrow MA$
Periclase + Protoenstatite	$M + MS \rightarrow M_2S$
Forsterite + Cristobalite	$M_2S + S \rightarrow 2MS$
Corundum + Cristobalite	$3A + 2S \rightarrow A_3S_2$
Spinel + Cristobalite	$2MA + 5S \rightarrow M_2A_2S_5$
Periclase + Cristobalite	$M + S \rightarrow MS$ $2M + S \rightarrow M_2S$

Perhaps the most interesting situations are when the construction lines cross one or more alkemade lines. In those cases, upon sufficient heating, the mixture will react to form the two compounds at the ends of the alkemade line. Once again, a stoichiometric mixture would result in the formation of only the two compounds at the ends of the alkemade line. Excess of either of the mixture compounds will result in three phases in equilibrium. **Table 4** indicates all of the possible reactions in the system, in this case where two phases react to form two other phases.

In cases where the construction line crosses more than one alkemade, both reactions will likely occur, depending on local conditions. Eventually, equilibrium will be attained, resulting in three phases

Table 4. Reactions between binary mixtures in the MAS system

Binary Reactants	Stoichiometric Reactions
Protoenstatite + Mullite	$16MS + 2A_3S_2 \rightarrow 5M_2S + 3M_2A_2S_5$ $3MS + A_3S_2 \rightarrow MA + M_2A_2S_5$ $52MS + 19A_3S_2 \rightarrow 16M_2A_2S_5 + 5M_4A_5S_2$
Protoenstatite +Alumina	$8MS + 2A \rightarrow 3M_2S + M_2A_2S_5$ $5MS + 5A \rightarrow 3MA + M_2A_2S_5$ $16MS + 19A \rightarrow 2M_2A_2S_5 + 3M_4A_5S_2$ $4MS + 8A \rightarrow A_3S_2 + M_4A_5S_2$ $2MS + 5A \rightarrow A_3S_2 + 2MA$
Protoenstatite + Sapphirine	$40MS + 2M_4A_5S_2 \rightarrow 19M_2S + 5M_2A_2S_5$ $5MS + 5M_4A_5S_2 \rightarrow 19MA + 3M_2A_2S_5$
Protoenstatite + Spinel	$10MS + 2MA \rightarrow 5M_2S + M_2A_2S_5$
Forsterite + Mullite	$15M_2S + 10A_3S_2 \rightarrow 16MA + 7M_2A_2S_5$ $13M_2S + 10A_3S_2 \rightarrow 4M_4A_5S_2 + 5M_2A_2S_5$
Forsterite + Alumina	$5M_2S + 10A \rightarrow 8MA + M_2A_2S_5$ $2M_2S + 5A \rightarrow M_4A_5S_2$ $2M_2S + 7A \rightarrow 4MA + A_3S_2$
Periclase + Cordierite	$10M + M_2A_2S_5 \rightarrow 5M_2S + 2MA$
Periclase + Mullite	$7M + A_3S_2 \rightarrow 2M_2S + 3MA$ $15M + 5A_3S_2 \rightarrow 2M_2A_2S_5 + 11MA$ $52M + 21A_3S_2 \rightarrow 4M_2A_2S_5 + 11M_4A_5S_2$
Periclase + Sapphirine	$5M + M_4A_5S_2 \rightarrow 2M_2S + 5MA$ $5M + 5M_4A_5S_2 \rightarrow 2M_2A_2S_5 + 21MA$
Cristobalite + Sapphirine	$26S + 3M_4A_5S_2 \rightarrow A_3S_2 + 6M_2A_2S_5$

based upon the relative amounts of the starting phases. Global reactions can be written to reflect the final phase assemblages.

The simplicity of these stability relationships is quite powerful in new systems or systems that haven't been widely studied. By crafting a series of experiments, the entire set of stability (alkemade) lines can quickly be generated.

An interesting effect occurs in systems having significant but not infinite, solid solution. In these cases, the reactions that occur can be determined as before. However, the resulting phases do not have the chemistry of the stoichiometric compound. The effect is that the alkemade lines are shifted away from the location of the compound. The phase diagram highlighting these lines is included as **Figure 3**. In this way the solid solution just occurs as the phase forms. The specific location of these solid-solution-shifted alkemades cannot be predicted. Often there is more than one alkemade line associated with the same two oxides. These are indications of specific chemistries that are in equilibrium.

As examples, consider three triangles that are present near the corners of the MAS system. The first to consider is the triangle between MgO, $2MgO•SiO_2$ and $MgO•Al_2O_3$. Based on the information indicated, no significant solid solution exists, so the three alkemade lines terminate on the stoichiometric oxide chemistries. The second is the $MgO•SiO_2$, SiO_2 and $2MgO•2Al_2O_3•5SiO_2$ triangle. In this case, the alkemades terminate on the oxides SiO_2 and $MgO•SiO_2$ indicating that they are both stoichiometric oxides. Two alkemade lines terminate at a composition that is very far from the stoichiometric cordierite position. Some of the $MgO•SiO_2$ and SiO_2 reached with $2MgO•2Al_2O_3•5SiO_2$ to form a solid solution, creating non-stoichiometric cordierite. The third to consider is the triangle between $MgO•Al_2O_3$, $3Al_2O_3•2SiO_2$ and Al_2O_3. In this case Al_2O_3 is the only

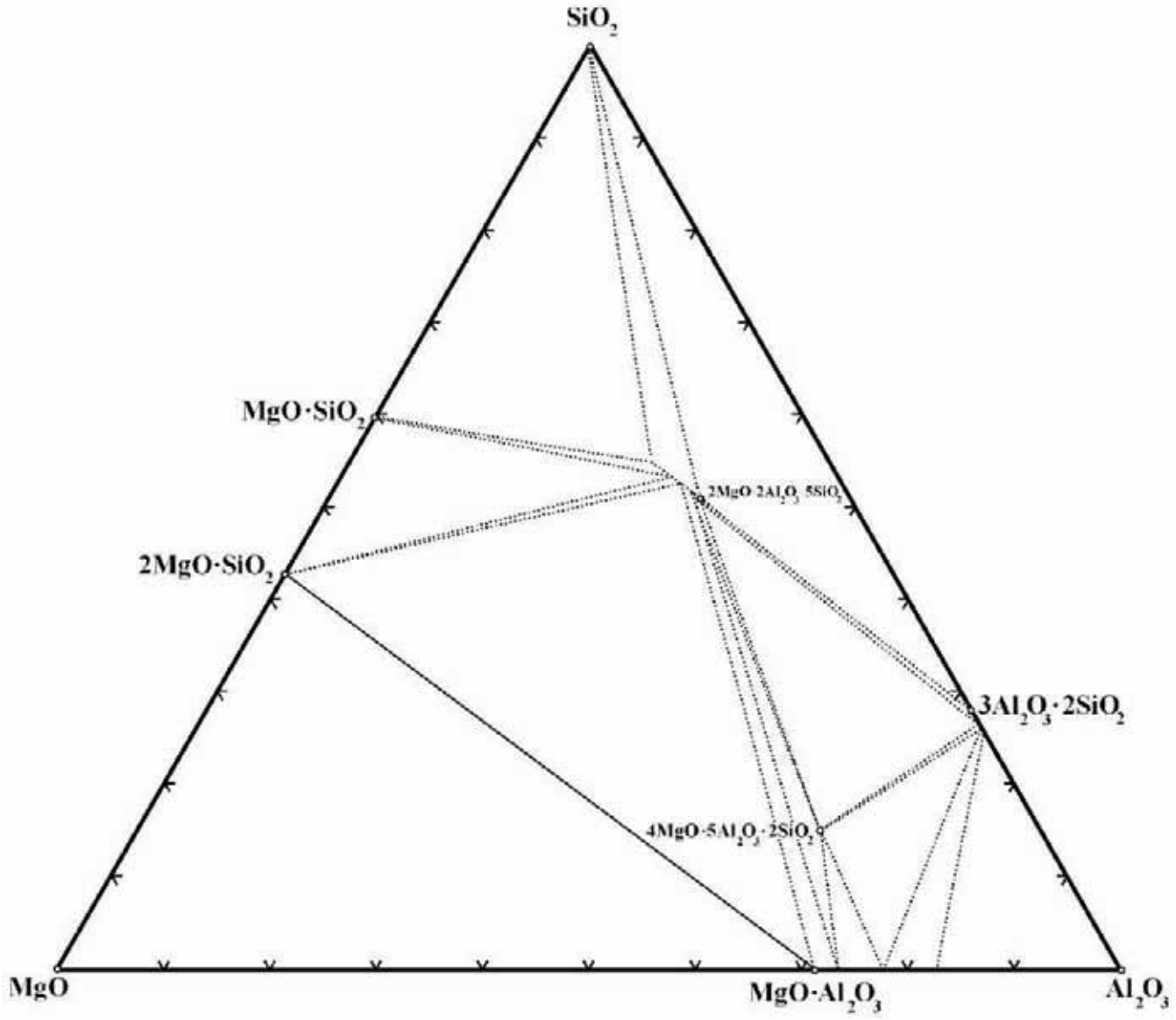

Figure 3. Ternary phase compatibility diagram of the MgO-Al_2O_3-SiO_2 system showing alkemades with solid solution considered.

stoichiometric phase as both spinel and mullite become rich in Al_2O_3. The spinel non-stoichiometry is quite significant, a fact that was discussed in detail in previous installments of *Phase Rules* [1].

It is important to pause to ensure that compositions can be determined in the system. **Figure 4** is included to highlight the use of the ternary lever rule. Two points are included, labeled as A and B. With the point labeled A, determination of the overall composition was accomplished by applying the ternary inverse lever rule. The most straightforward application of the rule is to construct two lines through the point of interest that are parallel to the other two sides of the triangle. This procedure sections the line into three segments that then represent the concentration of the oxides at the corners of the triangle. The smallest segment (10% of the total) corresponds to the amount of SiO_2, while the longest corresponds to the amount of MgO. The middle segment always corresponds to the far point of the triangle, in this case Al_2O_3.

This procedure can be applied to any triangle, not just to the large system triangle. Point B is used to highlight the use of the ternary lever rule to a triangle that is not equilateral. In this case, the two lines are constructed parallel to the short sides, so that the longest side is sectioned into three parts (provides the greatest precision). The composition selected turns out to be 25% mullite, 40% sapphirine and 35% cordierite.

Of course, both of these compositions could be considered in the other fashion and although the construction lines are left for the reader to add, the concentrations are indicated near the top of **Figure 4.**

The ternary lever rule is extremely useful in determining the concentrations of the various phases present, the composition of a liquid and the weight concentration of components in a solid phase. For instance, the oxide cordierite ($2MgO•2Al_2O_3•5SiO_2$) is 2/9 MgO or 22 mol%, 2/9 Al_2O_3 or 22 mol% and 5/9 SiO_2 or 56 mol%. Determining the weight percents of the three components could be accomplished by considering the molecular weights and converting the mol% values or the ternary lever rule can be applied at that composition on the phase diagram yielding values of 14 wt% MgO, 35 wt% Al_2O_3 and 51 wt% SiO_2.

Alkemade lines are also critical in defining critical points for temperature changes in a system. In this instance Alkemade theorized that the location at which an alkemade line and its corresponding

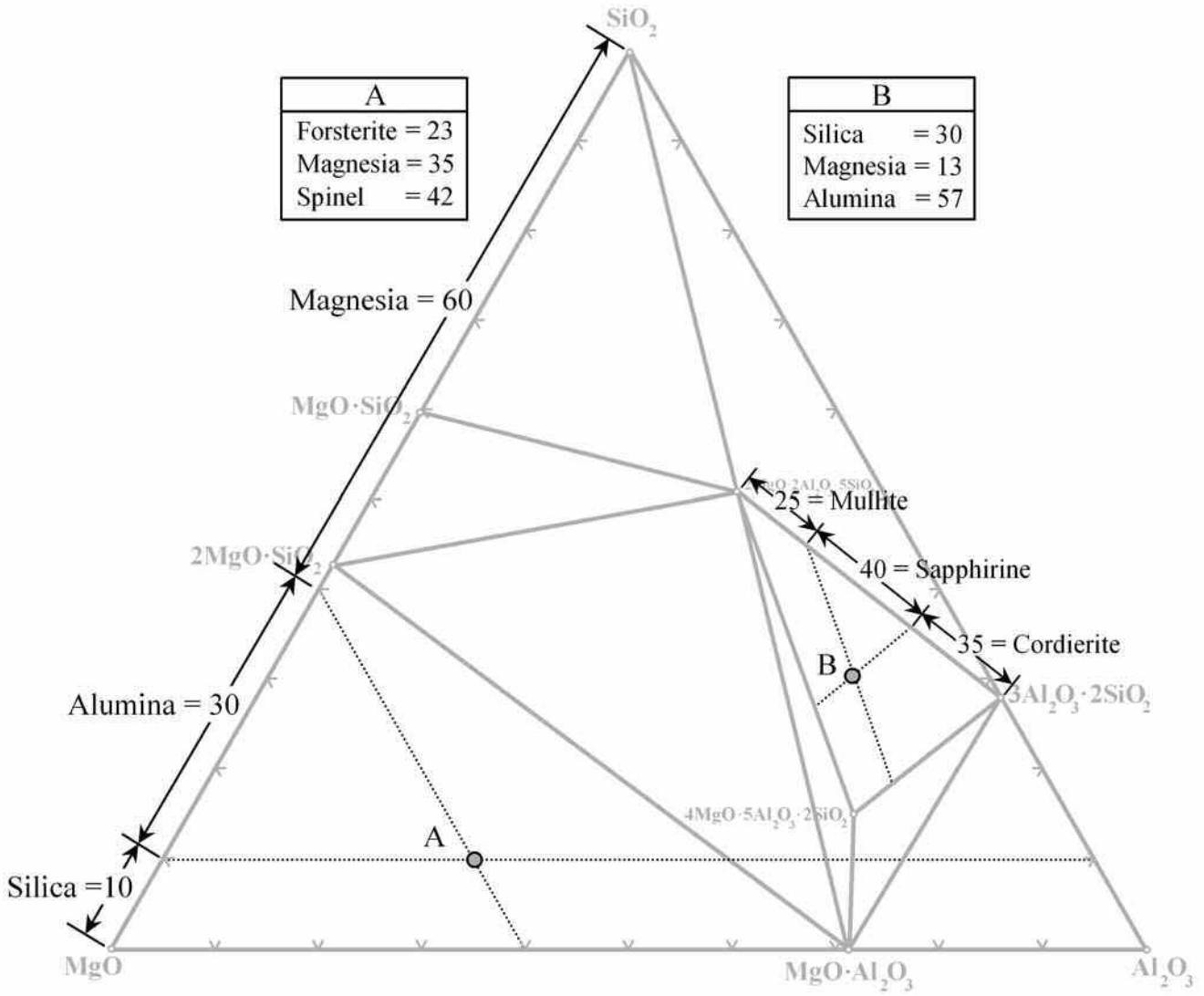

Figure 4. Ternary phase diagram illustrating the use of the ternary inverse lever rule to determine the composition associated with two particular chemistries (A and B) within the MAS system in terms of the system components as well as the phase assemblage within the local alkemade triangle.

boundary curve (the boundary between the two phases of interest) cross was a special point at which the alkemade line was at a minimum in temperature while the boundary curve was at a maximum (topographically analogous to a saddle point). If the curve/line combination does not cross, either or both should be virtually extended until they intersect, and the rule then applied.

Alkemade lines combine to form triangles that have additional significance. The triangles not only define the three phases that are stable together, they help to establish the invariant temperature associated with all chemistries within the triangle. Within the last statement is a critical principle of ternary phase equilibria; all compositions within an alkemade triangle are associated with the same final invariant reaction. Although different chemistries may progress through very different reaction sequences, all will go through final solidification at the same invariant point. That invariant is defined as the point where the three phase fields (representing the compounds at the three corners of the alkemade triangle) come into contact. **Figure 5** provides this type of analysis for each of the alkemade triangles in the system. Here each alkemade triangle is indicated by a spelled number, while the invariant associated with a given triangle is circled and labeled with the corresponding numeral. In each of the three examples, the associated invariant is indicated by the number associated with the numbered triangle.

The nine ternary points in the system are listed in **Table 5** along with the invariant type, temperature and reaction. Only three eutectic and six peritectic ternary invariants exist in the MAS system. Note that invariant (6), a peritectic at 1482ºC is associated with two separate reactions. The particular reaction that should be considered is dependent upon the alkemade triangle in which the initial composition was located. Typically peritectic reactions involve two boundary curves entering the invariant and one exiting. In this special case, one boundary curve enters the invariant and two exit the invariant. In this case, the only way to know which exit is appropriate is to consider the starting alkemade triangle.

Once the final solidification conditions have been established, the question of how the overall crystallization proceeds remains. Upon selecting a chemistry to be considered, the final liquid crystallization location is defined by the alkemade triangle in which it resides as above. The next step is to define the initial crystals that will form from the melt of interest. This is a simple matter of locating the initial chemistry and determining the phase field in which it is present.

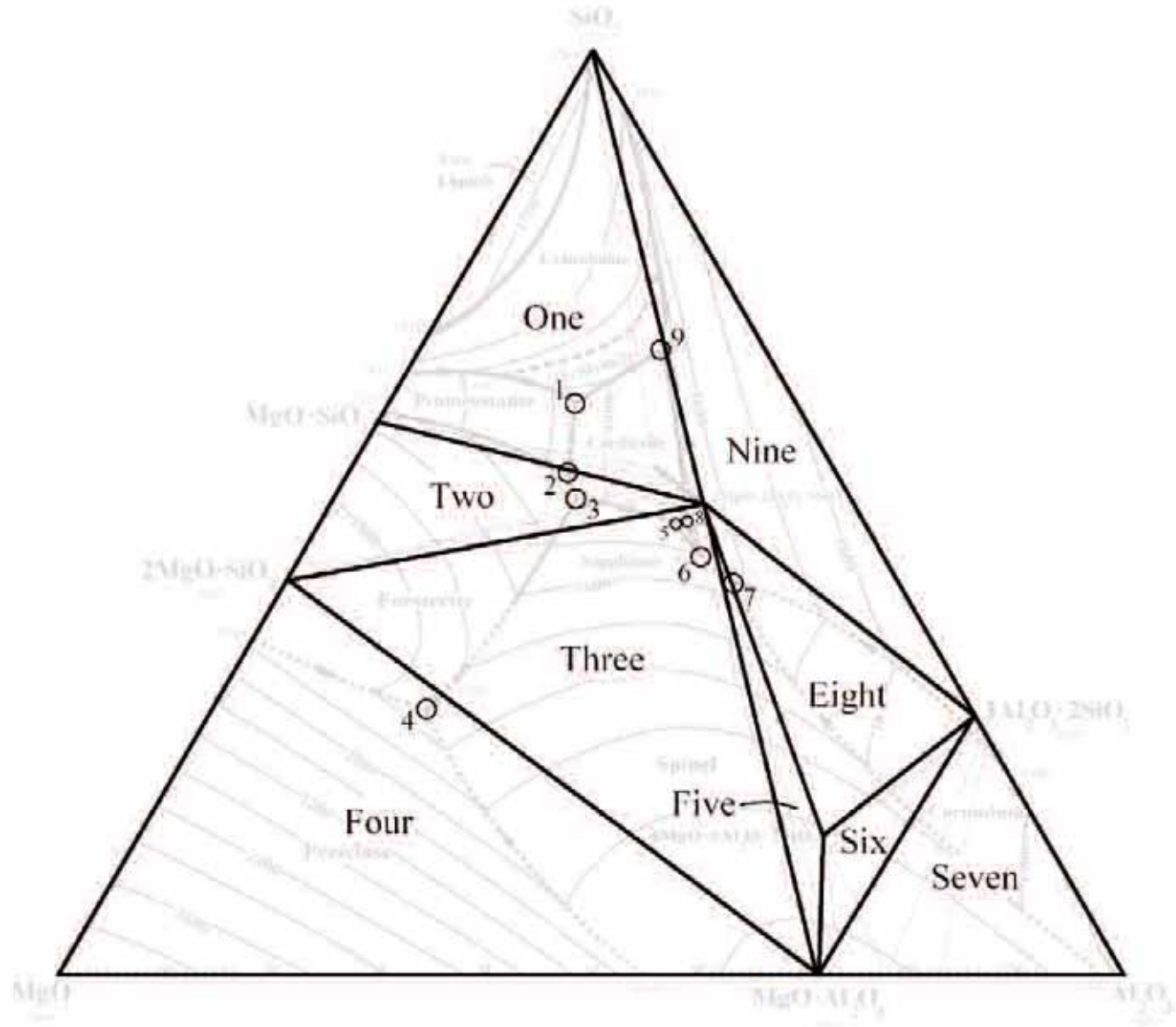

Figure 5. Ternary phase diagram of the MAS system highlighting the nine alkemade triangles and each of their associated final invariants. (Note: the alkemade triangle labels are spelled, e.g. "Ten", while their associated invariants are identically enumerated, e.g. "10".)

Table 5. Ternary invariant reactions in the MAS system

Label	Type	Temp	Reaction on Cooling
1	Eutectic	1355°C	L → Tridymite + Protoenstatite + Cordierite
2	Eutectic	1365°C	L → Forsterite + Protoenstatite + Cordierite
3	Peritectic	1370°C	L + Spinel → Forsterite + Cordierite
4	Eutectic	1710°C	L → Periclase + Forsterite + Spinel
5	Peritectic	1453°C	L + Sapphirine → Spinel + Cordierite
6	Peritectic	1482°C	L + Mullite + Spinel → Sapphirine
7	Peritectic	1578°C	L + Corundum → Mullite + Spinel
8	Peritectic	1460°C	L + Mullite → Sapphirine + Cordierite
9	Peritectic	1440°C	L + Mullite → Tridymite + Cordierite

For example, consider the chemistry indicated by (X) in Figure 6. It is in the periclase phase field, so periclase (MgO) will be the first oxide to crystallize upon cooling. As the periclase crystallizes from the liquid, it is obvious that the liquid will become lower in MgO concentration; the change in liquid chemistry being indicated on the diagram as the bold line moving directly away from the chemistry that is crystallizing (MgO) and running through the initial chemistry of the melt (X). The specific liquid composition can be determined by applying the ternary lever rule at the temperature of interest. For example, upon cooling to 2200ºC, the liquid composition is indicated by the chemistry of point "b". The amount of liquid and periclase in equilibrium at this temperature is determined by dividing segments a-X and X-b by a-b, respectively.

Periclase crystallization continues with cooling until the liquid chemistry reaches the boundary curve between periclase and spinel at point "c". Further cooling results in the crystallization of two solids, periclase and spinel. It is important to realize that the overall chemistry has not changed, and thus analysis of this type is termed isoplethal or of constant chemistry. This is key as the liquid and solid are complementary in combined systems. As one increases in amount or chemistry the other must adjust so that the overall chemistry and mass is unchanged. Graphically, the effect is interesting, as a construction line can be drawn from a selected liquid chemistry back to

the original composition and then extended to the alkemade line that connects the two solids crystallizing. At ~1960ºC (point c) the analysis is identical to that of point "b" with the exception that one realizes at equilibrium an infinitesimal amount of spinel coexists with periclase and liquid.

Continuing with the melt of composition X and now cooling to 1900ºC (point "d"). While the composition of the liquid is that of point "d", the construction or tie line used to determine the solid:liquid proportion is now d'-d where d' terminates on the periclase-spinel alkemade joining the two phases now crystallizing. The amount of liquid is equal to the section length from solid to the initial composition (d'-X) divided by the total section length (d'-d, solid to liquid). Conversely, the amount of solid would be the section length from liquid to initial composition (X-d) divided by the total (d'-d). Construction lines are included on **Figure 6** to show this type of analysis.

The previous calculation provides only the total solid content; so determining the ratio of the two solids present would establish the specific concentrations. The point where the construction line contacts the alkemade line (point d') bisects the alkemade line into segments that can be used to determine the ratio of the solids, periclase and spinel. Once again, it is the inverse lever rule that applies using segments a-d', d'-a', and the alkemade a-a'. The concentration of a particular solid is obtained by multiplying that ratio by the total solid concentration determined previously.

Spinel and periclase continue to crystallize until the system is cooled to the eutectic at 1710ºC (point e). This eutectic at the junction of three phase fields (periclase-spinel-forsterite) is the invariant for the alkemade triangle containing composition X. At 1710ºC the isoplethal analysis is analogous to that at point "d" with the understanding that an infinitesimal amount of forsterite is also included in the solid along with periclase and spinel, and that the liquid is of composition "e". Although isoplethal analysis of any composition initiating within the periclase-spinel-forsterite alkemade triangle will have identical liquid chemistry (e) on cooling to 1710ºC, the amount of this eutectic liquid will vary. Chemistries located closer to the eutectic

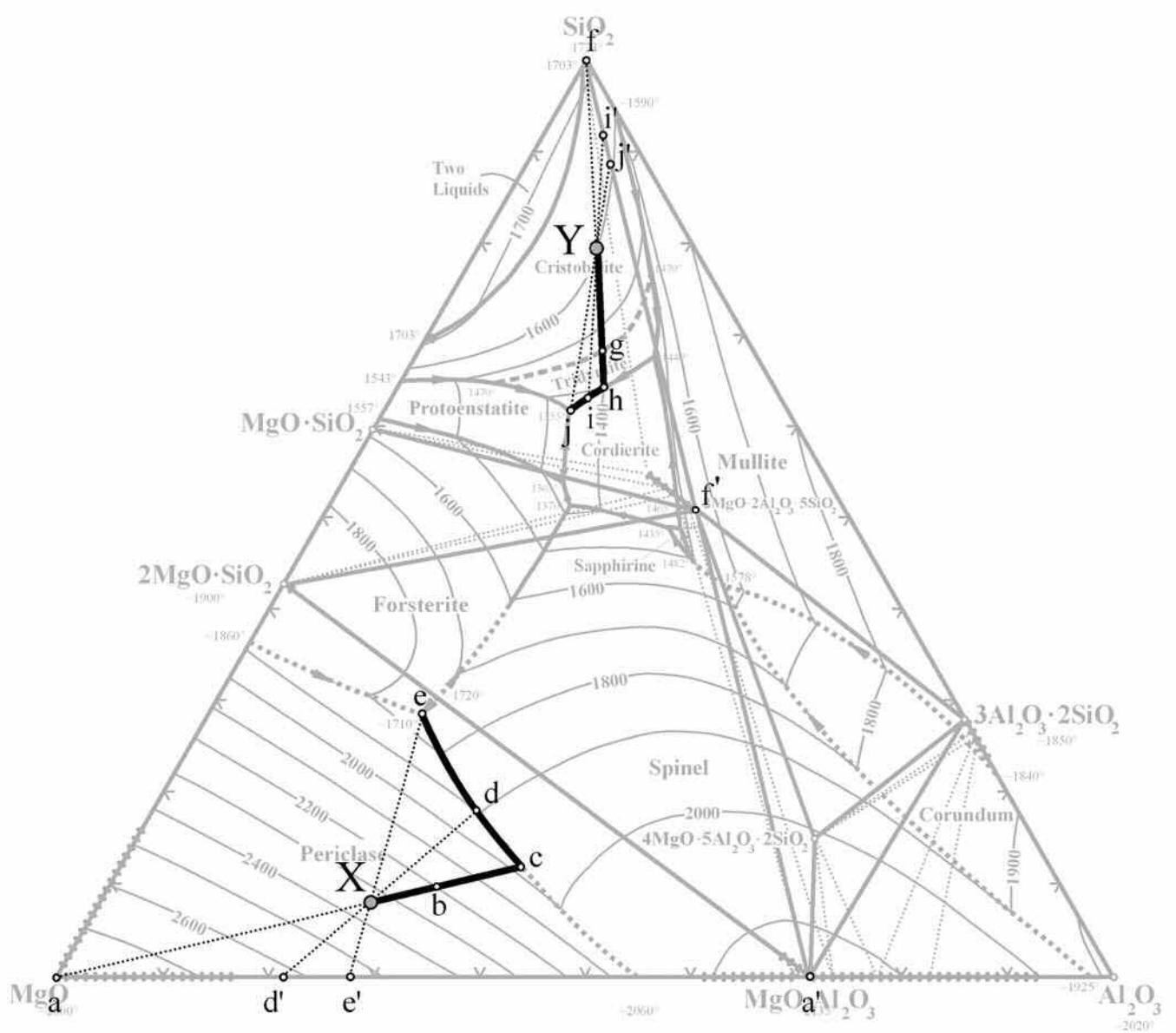

Figure 6. The crystallization of two chemistries within the MAS system is illustrated. (Points X and Y). Construction lines are included at various temperatures of interest; and, the chemistry of the liquid phase on cooling is highlighted by a bold line for each case. Associated calculations are included as **Tables 6** and **7** for points X and Y, respectively.

will have a greater proportion of liquid at ~1710ºC than compositions nearer the apacies of the alkemade triangle.

Cooling beyond 1710ºC will yield a completely crystallized system. The eutectic liquid, in this case 28% of the total mass, crystallizes into periclase, spinel, and forsterite with proportions that can be determined using the ternary lever rule within the alkemade triangle at point "e". These crystals resulting from the crystallization of eutectic liquid are referred to as eutectic crystals. The crystalline matter that was in equilibrium with the eutectic liquid at the eutectic temperature are referred to as primary crystals. In terms of microstructure, a melt of composition X slowly cooled to room temperature would have ~2/3^{rds} of the mass attributable to larger primary crystals of periclase and spinel in a eutectic matrix accounting for ~1/3rd of the total mass and consisting of smaller crystals of periclase, spinel, and forsterite. **Table 6** provides details for the solidification of chemistry in X in **Figure 6** at the selected temperatures of interest. Measurements of this type are difficult to make with precision. All values should be assumed to be +/- ~3%.

The isoplethal analysis of composition Y in **Figure 6** proceeds similarly to that of composition X with a couple of distinctions. At ~1470ºC (point g) there is a polymorphic transformation and the stable solid phase is tridymite rather than cristobalite. At ~1400ºC (point h) the cordierite phase field is reached. With continued cooling to the eutectic at ~1355ºC (point j), tridymite and cordierite are crystallizing; therefore, proportional analysis in this temperature range uses the S-$M_2A_2S_5$ alkemade (f-f') on the interior of the MAS parent diagram. Below 1355ºC, the eutectic liquid of composition "j" crystallizes into tridymite, cordierite, and protoenstatite. The isoplethal analysis of composition Y is detailed in **Table 7**.

Although many crystallization paths are quite simple in ternary systems, others are considerably more involved. As examples, two additional paths are included as **Figure 7**. Although a bit more complicated, isoplethal analysis proceeds in the same manner. As before: (1) the final solidification is determined from the alkemade triangle and its associated final invariant; (2) the initial crystallization is defined by the primary phase field of the overall composition with the liquid composition moving directly away from the solid phase composition until a boundary curve is encountered; then (3) the boundary curves are followed (usually) to the final invariant using the appropriate alkemade to determine proportions.

The first two steps are typically straightforward. The third is where the complications arise. In the example of composition P in **Figure 7**, the path initially moves directly away from spinel ($MgO•Al_2O_3$) until the spinel-corundum boundary curve is reached at ~1820°C. From here the liquid composition follows the phase boundary as before and the spinel-corundum alkamade (a-a') is used to determine proportions. Upon cooling to 1578°C, the liquid reaches a triple point where the boundary curves spinel-corundum, corundum-mullite and spinel-mullite intersect at point "c". This invariant point, a peritectic, is not the final invariant for this particular chemistry; instead it is just a thermal arrest point along the way. From here with further cooling, the liquid chemistry will continue along the spinel-mullite boundary curve from "c" to "d".

Progressing through the peritectic invariant point at "c" involves the elimination corundum. This is accomplished by the invariant reaction:

Alumina + Liquid → Spinel + Mullite

Table 6. Isopelthal calculations for point X in Figure 6

	State Proportions			Phase Proportions		
Temperature	Phase	Calculation Method	Weight Percent	Species	Calculation Method	Weight Percent
2350°C (Point X)	Liquid	Inspection	100%	Magnesia Alumina Silica	MAS-Δ at Point X	66% 26% 8%
	Solid	Inspection	<< 1%	Periclase	Inspection	100%
2200°C (Point b)	Liquid	a-X / a-b	82%	Magnesia Alumina Silica	MAS-Δ at Point b	62% 28% 10%
	Solid	X-b / a-b	18%	Periclase	Inspection	100%
1960°C (Point c)	Liquid	a-X / a-c	67%	Magnesia Alumina Silica	MAS-Δ at Point c	52% 36% 12%
	Solid	X-c / a-c	33%	Periclase Spinel	Inspection	100% << 1%
1900°C (Point d)	Liquid	d'-X / d'-d	46%	Magnesia Alumina Silica	MAS-Δ at Point d	52% 36% 12%
	Solid	X-d / d'-d	54%	Periclase Spinel	d'-a' / a-a' a-d' / a-a'	70% 30%
+1710°C (Point e) > Eutectic	Liquid	e'-X / e'-e	28%	Magnesia Alumina Silica	MAS-Δ at Point e	52% 20% 28%
	Solid	X-e / e'-e	72%	Periclase Spinel	e'-a / a-a' a-e' / a-a'	61% 39%
-1710°C (Point e) < Eutectic	Eutectic Crystals	e'-X / e'-e	28%	Forsterite Periclase Spinel	Phase Balance	66% 5% 29%
	Primary Crystals	X-e / e'-e	72%	Periclase Spinel	e'-a / a-a' a-e' / a-a'	61% 39%

Table 7. Isopethal calculations for point Y in Figure 6

	State Proportions			Phase Proportions		
Temperature	Phase	Calculation Method	Weight Percent	Species	Calculation Method	Weight Percent
1600°C (Point Y)	Liquid	Inspection	100%	Magnesia Alumina Silica	MAS-Δ at Point Y	9% 11% 80%
	Solid	Inspection	<< 1%	Cristobalite	Inspection	100%
1470°C (Point g) Polymorphic Transformation	Liquid	f-Y / f-g	65%	Magnesia Alumina Silica	MAS-Δ at Point g	14% 18% 68%
	Solid	Y-g / f-g	35%	Cristobalite Tridymite	Inspection	100% << 1%
1400°C (Point h)	Liquid	f-Y / f-h	57%	Magnesia Alumina Silica	MAS-Δ at Point h	15% 20% 65%
	Solid	Y-h / f-h	43%	Tridymite Cordierite	Inspection	100% << 1%
1380°C (Point i)	Liquid	i'-Y / i'-i	42%	Magnesia Alumina Silica	MAS-Δ at Point i	17% 19% 64%
	Solid	Y-i / i'-i	58%	Tridymite Cordierite	i'-f' / f-f' f-i' / f-f'	83% 17%
+1355°C (Point j) >Eutectic	Liquid	j'-Y / j'-j	34%	Magnesia Alumina Silica	MAS-Δ at Point j	21% 17% 62%
	Solid	Y-j / j'-j	66%	Tridymite Cordierite	j'-f' / f-f' f-j' / f-f'	77% 23%
-1355°C (Point j) < Eutectic	Eutectic Crystals	j'-Y / j'-j	34%	Tridymite Cordierite Protoenstatite	Phase Balance	17% 50% 33%
	Primary Crystals	Y-j / j'-j	66%	Tridymite Cordierite	j'-f' / f-f' f-j' / f-f'	77% 23%

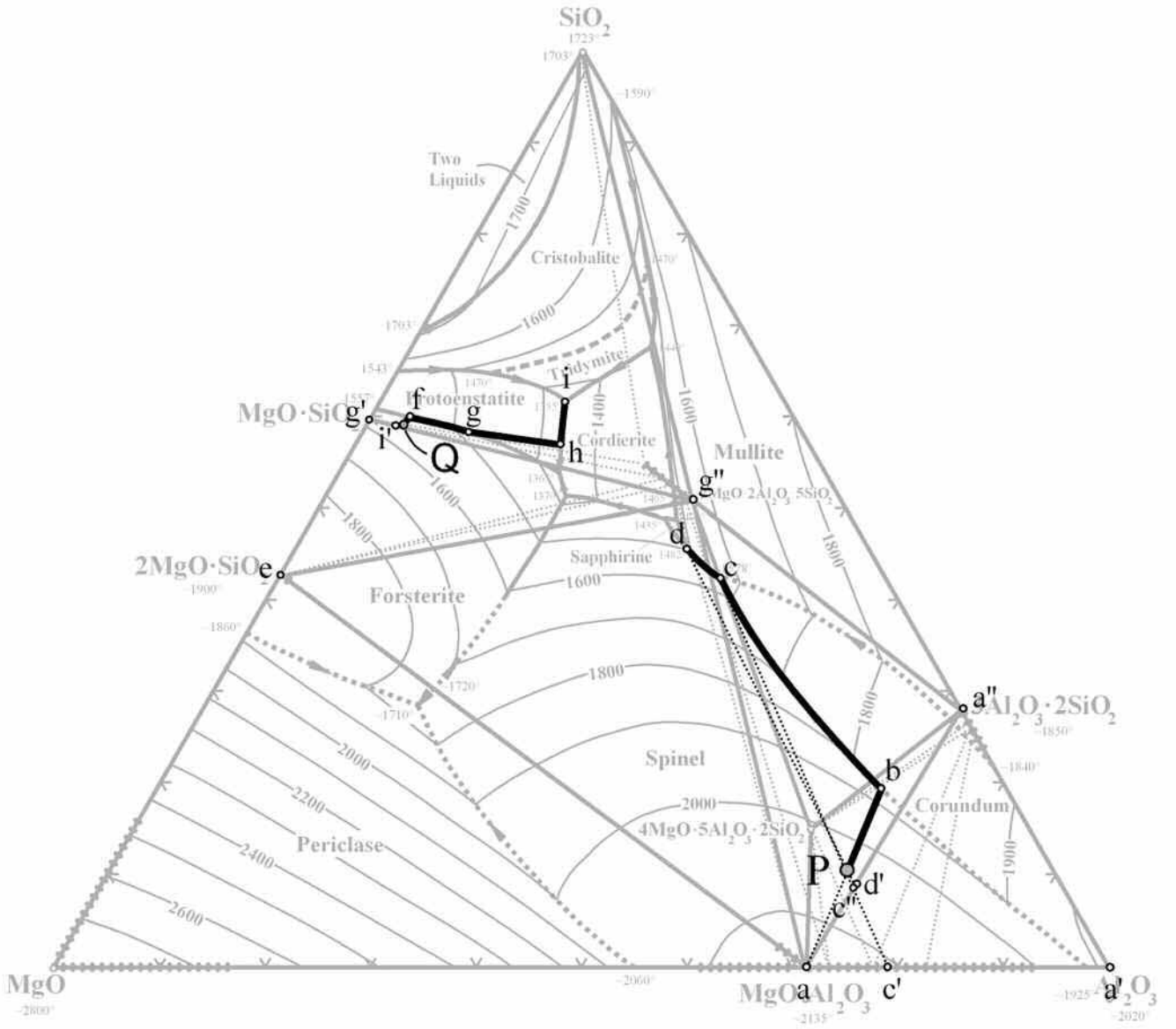

Figure 7. The crystallization of two chemistries within the MAS system is illustrated involving an intermediate peritectic reaction in the case of point "P" and complete resorption in the case of point "Q". Construction lines are included at various temperatures of interest; and, the chemistry of the liquid phase on cooling is highlighted by a bold line for each case. Associated calculations are detailed in **Tables 8** and **9** for points P and Q, respectively.

GLOSSARY OF TERMS

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

Alkemade line – A straight line joining the compositions of two phases that share a boundary curve.

Alkemade Triangle – Combination of three alkemade lines that define the final solidification invariant.

Congruent Phases – Pair of phases that define a phase field. A tie-line between conjugate phases is used to determine the relative amounts of each.

Crystallize – Partial solidification of a liquid.

Eutectoid – A reversible reaction between two solid phases that upon heating forms a single solid phase with a different composition.

Isotherm – A type of contour line or surface connecting points of equal temperature on a phase diagram.

Peritectoid – A reversible reaction between two solid phases that upon cooling form a single solid phase with a different composition.

Resorb – A crystal that is dissolved back into the liquid phase.

Solid Solution – A solid phase containing more than one substance.

Ternary Lever Rule – Parallel lines drawn within a triangle cause the sides of the triangle to be divided into three segments that define the concentrations of phases present.

The time required to eliminate corundum is the thermal arrest period. On cooling the reaction is exothermic so the temperature of the system remains unchanged until, in this case, alumina is exhausted. It should be noted as well that thermal arrest periods also result in an abrupt change in the alkemade line used for proportional analysis. In this case, the solid composition "jumps" from the spinel-corundum alkemade (a-a') to the spinel-mullite alkemade (a-a''). Isoplethal analysis just before and just after the invariant supports the above reaction and highlights that although ~75% of the liquid is consumed in this process, the chemistry of the liquid remains constant. The details of the isoplethal analysis of point P are included as **Table 8.**

The second crystallization path for point Q of **Figure 7** goes through an interesting change where one phase is completely resorbed on cooling. This is a result of the crystallization path entering and then later leaving a boundary curve and travelling across a phase field in a similar fashion to the initial crystallization of a singe phase. Determining when complete resorption of a phase will occur is not necessarily obvious. Initially the path moves directly away from forsterite (point e) from Q until the forsterite-protoenstatite phase boundary is reached at ~1540°C (point f). As cooling progresses, the M_2S-MS alkemade (e-g') is used for determining proportions and forsterite is resorbed as protoenstatite crystallizes. Eventually at ~1480°C (point g), the isoplethal analysis shows that the solid phase consists of 100% protoenstatite and that all of the forsterite has been resorbed. As cooling continues further, only protoenstatite is crystallizing and therefore the liquid composition follows a path directly away from the MS composition and across the protoenstatite phase field from points "g" to "h" at ~1375°C. Here the MS-$M_2A_2S_5$ phase boundary is encountered and cordierite begins to crystallize with protoenstatite. From point "h" to the eutectic at point "i" the MS-$M_2A_2S_5$ alkemade (g'-g") is used for proportional analysis. Details of the isoplethal analysis of point Q are included as **Table 9**.

The next installment of *Phase Rules* will consider construction of isothermal and vertical sections.

REFERENCES

1. J. D. Smith, "Phase Equilibria Diagrams of Three Components – Systems Containing Limited (or no) Solid Solution", **14** [1], 17-22, (2009).
2. J. D. Smith, "Phase Equilibria Diagrams of Two Components - Systems Containing Solid Solutions", *RAN,* **12** [5], 13-21, (2007).
3. J. D. Smith, "Phase Equilibria Diagrams of Two Components", *RAN,* **11** [6] 5-9, (2006).
4. J. D. Smith, "Phase Equilibria Diagrams of One Component", *RAN*, **10** [6], 9-14, (2005).

Table 8. Isoplethal calculations for point P in Figure 7

Temperature	State Proportions: Phase	Calculation Method	Weight Percent	Phase Proportions: Species	Calculation Method	Weight Percent
2030°C (Point P)	Liquid	Inspection	100%	Magnesia Alumina Silica	MAS-Δ at Point P	19% 70% 11%
	Solid	Inspection	<< 1%	Spinel	Inspection	100%
1820°C (Point b)	Liquid	a-P / a-b	54%	Magnesia Alumina Silica	MAS-Δ at Point b	11% 69% 20%
	Solid	P-b / a-b	46%	Spinel Corundum	Inspection	100% << 1%
+1578°C (Point c) > Peritectic	Liquid	c'-P / c'-c	25%	Magnesia Alumina Silica	MAS-Δ at Point c	16% 42% 42%
	Solid	P-c / c'-c	75%	Spinel Corundum	c'-a' / a-a' a-c' / a-a'	73% 27%
-1578°C (Point c) < Peritectic	Liquid	c"-P / c"-c	6%	Magnesia Alumina Silica	MAS-Δ at Point c	16% 42% 42%
	Solid	P-c / c"-c	94%	Spinel Mullite	c"-a" / a-a" a-c" / a-a"	70% 30%
+1482°C (Point d) < Peritectic	Liquid	d'-P / d'-d	5%	Magnesia Alumina Silica	MAS-Δ at Point d	17% 37% 46%
	Solid	P-d / d'-d	95%	Spinel Mullite	c"-a" / a-a" a-c" / a-a"	69% 31%
-1482°C (Point d) > Peritectic	Peritectic Crystals	Phase Balance	21%	Sapphirine	Phase Balance	100%
	Primary Crystals	Phase Balance	79%	Spinel Mullite	Phase Balance	67% 33%

Table 9. Isopethal calculations for point Q in Figure 7

Temperature	State Proportions: Phase	Calculation Method	Weight Percent	Phase Proportions: Species	Calculation Method	Weight Percent
1560°C (Point Q)	Liquid	Inspection	100%	Magnesia Alumina Silica	MAS-Δ at Point Q	37% 3% 60%
	Solid	Inspection	<< 1%	Forsterite	Inspection	100%
1540°C (Point f)	Liquid	e-Q / e-f	95%	Magnesia Alumina Silica	MAS-Δ at Point f	36% 3% 61%
	Solid	Q-f / e-f	5%	Forsterite Protoenstatite	Inspection	100% << 1%
1480°C (Point g)	Liquid	g'-Q / g'-g	35%	Magnesia Alumina Silica	MAS-Δ at Point g	32% 10% 58%
	Solid	Q-g / g'-g	65%	Forsterite Protoenstatite	Inspection	<< 1% 100%
1375°C (Point h)	Liquid	g'-Q / g'-h	18%	Magnesia Alumina Silica	MAS-Δ at Point h	24% 19% 57%
	Solid	Q-h / g'-h	82%	Protoenstatite Cordierite	Inspection	100% << 1%
+1355°C (Point i) > Eutectic	Liquid	i'-Q / i'-i	6%	Magnesia Alumina Silica	MAS-Δ at Point i	21% 17% 62%
	Solid	Q-i / i'-i	94%	Protoenstatite Cordierite	g'-i' / g'-g" i'-g" / g'-g"	92% 8%
-1355°C (Point i) < Eutectic	Eutectic Crystals	i'-Q / i'-i	6%	Protoenstatite Cordierite Tridymite	Phase Balance	25% 58% 17%
	Primary Crystals	Q-i / i'-i	94%	Protoenstatite Cordierite	g'-i' / g'-g" i'-g" / g'-g"	92% 8%

Editor's Note

The figure on the right was incorrectly labeled in the Jan/Feb 2009 of *Phase Rules*. The corrected version is included here. Updated versions of all the *Phase Rules* installments will be placed on the website in the following weeks.

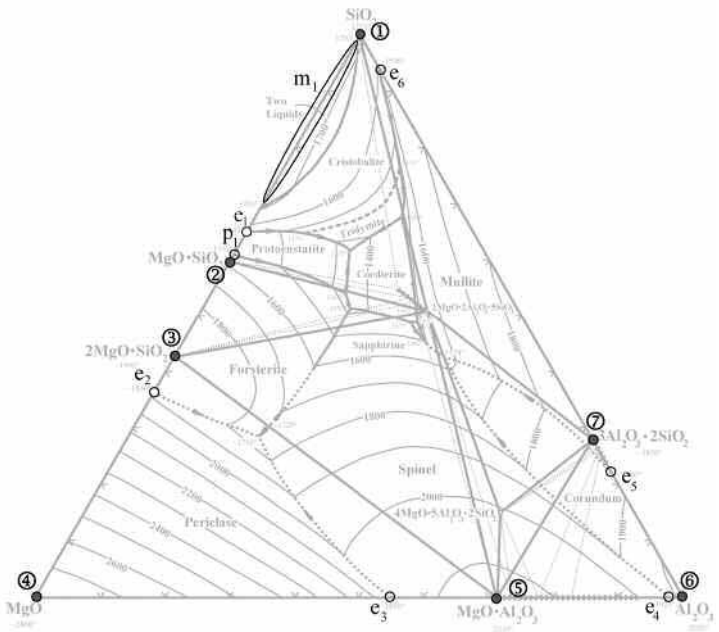

Figure 3. The $MgO-Al_2O_3-SiO_2$ ternary phase diagram highlighting the binary compounds and invariants. **Corrected from Jan/Feb 2009 issue.**

Attention UNITECR Attendees

We have been advised of an additional requirement to supplement the information in the January newsletter concerning Brazilian visas for UNITECR 2009. You must make entry into Brazil **within 90 days** of the date of the application approval. Therefore, you should not apply too early. Based on the October 13 date for the start of UNITECR, you may want to mark **July 15** on your calendars as the day to apply. That gives you the maximum time while meeting the 90 day requirement.

LINING DESIGN CONSIDERATIONS

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I will start out by saying that there are many ways of approaching a lining design and they are all correct as long as the end result fulfills the aim requirements.

Lining design considerations generally encompass many different parameters, only some of which are of a true refractory nature. They can be any one of the following, but generally encompass several competing requirements: product(s) to be made in the unit under repair or construction, maximum acceptable heat losses, maximum and average use temperatures, total refractory cost, speed of installation, available materials, length of time a unit will be in use before a maintenance outage is expected, who will install the refractories and their level of expertise, and so on. Most of these questions need to be addressed before a refractory lining design is considered complete.

OPERATIONAL PARAMETERS

The first issue to be ascertained is the operational parameters of the unit. If the new lining is purely a replacement of an existing one then the refractory requirements and challenges are known. Changes to the design will be small as they are only made to improve the overall operation, the environment, or to incorporate new refractory installation techniques. Unless there is an area which has seen unusual wear, design challenges are minimal.

On the other hand, if the unit represents a new installation, then many questions need to be considered such as, is a comparable unit in existence or is this a first of its kind, either because it is a new and experimental process or it is a pilot unit. Even if a comparable unit exists that will only provide an inkling of possible problem areas as each installation has its own challenges.

Among the operational parameters that require much consideration, as they impact refractory selection and performance, are process temperature and chemical environment. Process temperature encompasses many subcategories. The maximum expected temperature should be used as an overall requirement because if the refractory fails at lower temperatures then it will not be adequate. In addition it has to be ascertained how long the unit will be exposed to maximum temperature and if there will be localized areas which will be even hotter (I realize that this is a contradiction, but it is often encountered). The chemical environment can alter the initial refractory properties by modifying their thermal conductivity or lowering their melting point, changes that can dramatically affect performance.

Engineering parameters: Often the operational parameters and engineering parameters are discussed concurrently. By engineering parameters I mean the physical shape, size and location of unit. Although these issues are discussed early on, refractory knowledgeable personnel are often not involved in this step. Once shell dimensions and shape are committed to or under construction it is often too late for optimum refractory lining design as there may not be sufficient room for proper wall thickness, roof may not be able to support the weight required or unit shape is such that it precludes an easy drying, heating or lining configuration.

Although no unit lasts forever, provisions for its repair are often overlooked. The addition of walkways wide and strong enough for a loaded tow motor to use, openings to remove spent refractories and deliver new ones, and crane assists to properly place the refractories during a repair should all be incorporated into the original design.

REFRACTORY PARAMETERS

The first and most important parameter is, of course, what will take place in this unit. If it is melting or refining then the refractories need to be chemically compatible and inert with respect to the melt and slag, if it is a heating unit then the refractories need to be able to withstand the temperature and atmosphere, and so on. Selection of proper refractories requires deciding on the properties which are most important for success, and then determining what class of refractories embodies them and is most compatible. Often a compromise is required as opposing refractory properties are needed. Once the refractory that best accommodates the differing requirements has been selected then its proper installation method, advisability of using insulation, available method(s) for bringing the unit to use temperature, etc. should be considered. When similar refractory properties can be achieved using a brick, a castable or a plastic then a decision has to be made as to which material form will result in the best lining. One of the deciding criteria should be the level of installation expertise available, the reliability of the quality control of the manufacturer of the different materials, the likelihood of a controlled dry-out/heat up, etc. Cost of installation encompassing materials, forms, labor and dry out also need to be considered. This is also the time when provisions for ease of subsequent repairs should be incorporated into the design.

A unit which is to be used for an experimental process requires considerable imagination to design an optimum refractory lining as many parameters are unknown or poorly understood. In this case combining the best practices observed in units which have some overlapping characteristics with the new one should be taken into consideration, but novel concepts will also have to be developed to address expected challenges. It is imperative to be aware of the inherent risks involved in designing a lining for a completely new concept and one has to be ready to make adjustments quickly as knowledge is being developed.

There will be cases when the properties of the available refractories are not sufficient to properly address the operational requirements. In those cases a combination of engineering together with refractory design will be needed to solve the problem. An example might be temperatures exceeding the refractory's use limit in which case water cooling might need to be added for them to be successful.

I hope to have presented a summary of the most important issues that should be taken into account for a lining design. Obviously, most of these topics could be greatly expanded, but they were selected to provide a framework to use for decision making.

If you have comments about this column or suggestions for future topics please visit refractoryexpert.com. RAN

REFRACTORIES REVIEW, ALA AACHEN COLLOQUIUM'08

Charles E. Semler, Refractories Consultant, Semler Materials Services, Chandler, AZ, *CESemler@aol.com*

Charles E. Semler

The 51st Annual International Colloquium on Refractories was held at the Eurogress Center in Aachen, Germany, October 15-16, 2008. 54 papers were presented by speakers from 13 countries; the general theme of the Colloquium was "Refractories for Metallurgy", including Sessions on Steel topics, Unshaped Refractories, Properties of Sintering, Material Testing/Mechanical Properties, and Foundry. In addition to the presentations, there was an exhibition with 25 booths. Most of the papers (44%) dealt with monolithic refractories, and 41% focused on refractories for the steel industry. Carbon-containing refractories were discussed in 17% of the papers. Selected information from various papers presented in Aachen, and published in the Proceedings, is briefly summarized below, to provide a general sampling of the refractory activities around the world.

BACKGROUND/INTRODUCTION

The Steel Institute, VDEh reported that the steel industry started the year strong; orders were up 5% in the last quarter 2007, and 7% in the first quarter 2008; but the situation changed as the year went along. Steel production in Germany (1) was 12.1 mmt in the first quarter 2008, then 12.4 and 11.8 mmt in quarters two and three, respectively; the projected production for quarter four is about 10.4 mmt. So the steel production for the second half of the year declined 9% compared to the first half. The projected total steel production for Germany in 2008 is 46.68 mmt, which is 5% less than the total production in 2007.

The German Refractory Association (GRA) reported that their members were profiting from the strong steel market early in the year, and even before the decline in steel production, their margins were strongly affected by energy prices and raw materials issues. GRA noted that the price of major raw materials has increased 30-200%, since 2000, along with supply shortages and quality problems.

CONTINUALLY CHANGING REFRACTORY DEMANDS FOR STEEL

The plenary lecture by J. Schleuter, SMS Demag (Germany), provided current information about the adaptation of casting technology to the development of higher-grade steels, and the refractory needs related thereto. He used the CSP (thin-slab casting) and horizontal strip casting methods to illustrate how the increasing market demand for high-grade steels is causing the processes to be improved, and new processes to be developed, to meet the ever more stringent requirements for steel, which means that the refractory demands continue to increase. He also made the important point that the advances of steelmakers will be doomed to failure if the refractories don't fulfill the stricter requirements.

REFRACTORY ACTIVITIES FOR THE STEEL INDUSTRY

Historically the refractories industry has been successful in continually providing new and improved products, procedures, technology, cost reductions, and other benefits, to the steel industry. Considering the presentations at Aachen'08 it is clear that this historical trend still continues today.

The goal of implementing "endless life" castable linings in ladles has not been achieved because of insufficient castable durability, whereby the slag line still has to be lined with MgO-C bricks. So the need remains to develop an MgO-C castable that will work in the slag line, as well as special shapes like nozzles, well blocks, plugs, and slide gates. Authors from Refratechnik Steel and the Technical University at Freiberg reported their development of an MgO-C castable (up to 10%C), based on a novel bonding system (cold-setting resin and other graphitizable carbon). Field-testing is to be done soon, to confirm that the promising lab results will likewise result in good performance in actual service.

Several papers on slag practices revealed developments that result in significant practical benefits, and cost savings. A new synthetic flux (CMA – calcia magnesia alumina), discussed by Kerneos, showed reduced corrosion of MgO-C brick; i.e., 25% less than a CaF_2 practice and 15% less than a calcium aluminate practice. Pilsen Steel, Czech Republic reported the successful use of foamy slag practice in two 70 ton electric arc furnaces with two sidewall burners each. The refractory heats per campaign increased from 106 to 217 (105%), and the quantity of maintenance refractory decreased 72%, from 4.42 tons per ton of crude steel to 1.22 tons. And, the furnace tapping time was reduced from 5 hrs to 3 hrs.

G. Buchenebner, et al., RHI, reported that the modes of wear of MgO-C bricks in steel ladles are very complex, including interactive mechanical, thermal, and chemical effects. Because the thermomechanical behavior of MgO-C refractories is of crucial importance in minimizing and controlling the detrimental effects in service, it is important to know that the thermomechanical behavior can be influenced by designing MgO-C bricks with the proper microstructure. Their research showed that the choice of proper additives (Al and alumina), for car-

bide, nitride, and spinel formation, and the proper expansion of MgO-C bricks could be affected throughout a ladle campaign. This work by RHI resulted in the development of a new generation of MgO-C products.

MONOLITHIC REFRACTORY TOPICS

Given the great importance of the nozzleman to the installation rate, quality, and integrity of gunned/shotcast installations, it is important to recognize that specific training and certification could help the industry to progressively reduce the number of installation problems, linings with shortened life, costly lawsuits, etc. A. Zülch, DGFS (German Society for Refractory & Chimney Construction) reported a program of personal training, which includes a course with half practical and half theoretical content, and exams on both the practical and theoretical information, for qualifying and certifying people for installation of refractory by shotcasting.

C. Paglioso, et al., Magnesita, reported the development and successful use of a new resin-bonded MgO-C castable that comes to the job site ready-to-use (R2U) for filling the 50-80 mm gap when a BOF converter bottom is replaced. It is planned that this R2U castable will also be used for hot repairs of well/plug blocks in ladles and critical wear areas in BOFs.

Refractory companies have always paid close attention to raw materials, because they are the lifeblood of the industry. But now there are a variety of reasons (cost, availability, quality, innovation, etc.) why raw materials are getting even more attention. Pertinent to the increased adjustment/substitution of raw materials in product formulations, H. Fryda, et al., Kerneos, discussed a new calcium aluminate binder which helps to minimize castable setting variability when used with fillers like silica fume and natural aggregates like bauxite and andalusite. This new binder offers more options, and flexibility, for making formulation changes. Aggregates, which are often considered to be inert, are not neutral with respect to castable rheology and cement hydration.

BENEFICIAL EFFECT OF REFRACTORY ADDITIVES

Over the decades, there are countless examples where the use of one or more additives, in major, minor, or trace amount, has resulted in significant improvement of a refractory, e.g. fumed silica addition to 90% alumina, and trace additions to high-tech castables. Several examples were reported at Aachen'08, such as:

Aneziris, et al., ICGCM, Freiberg, reported their research to improve the thermal shock resistance of alumina with the addition of titania and zirconia, which result in the formation of aluminum titanate, zirconium titanate, and/or destabilization of zirconia. These reactions result in the desirable formation of microcracks in the alumina matrix, and the associated decrease in Young's modulus.

F. Golestani-Fard, Iran Univ. of Science & Technology studied the mineralizing effects of nano-boehmite (AlOOH) on spinel formation in MgO and Alumina-MgO mixes. The results showed that the presence of nano-boehmite, (1) promoted the formation of spinel at <700°C (vs. 1000°C otherwise, for example), and (2) retarded the formation of CA_6.

Y.T. Lim, et al., POSCO, discussed the properties of high alumina (>90%) brick, based on fused alumina, with added fused silica and mullite. They determined that the crushing and flexural strength, hot MOR, and thermal shock resistance could be improved with optimum addition (not specified) of fused silica. And likewise, the optimum addition (not specified) of mullite resulted in high strength and excellent thermal shock resistance.

R. Kartik, et al., Tata Refractories, reported on the beneficial effects of adding an unspecified metal (up to 2 wt.% to silica brick composed of quartzite, lime slurry (3 wt.%), and iron oxide (1 wt.%). Testing after drying and firing (1430°C for 35 hrs) showed that increased metal addition resulted in lower porosity (22.5% to 18.5%), increased crushing strength (37 to 51 MPa), and lower thermal expansion because of decreased cristobalite and increased tridymite.

DUE TO GLOBALIZATION – BUYERS BEWARE

Today's refractory buyers and sellers/manufacturers operate in a global marketplace. Hence it is necessary to understand that there is a very important need to compare the quality and properties of refractories from different countries (which use different test standards), to achieve the proper "apples-to-apples" comparisons. Krause and Krebs, of Forschungsgemeinschaft Feuerfest and Sankt Augustin, respectively, compared the testing of bulk density, cold modulus of rupture (CMOR) and crushing strength, and permanent linear change, for a medium cement castable to determine the actual differences. **Table 1** illustrates the range of CMOR results (after firing at 1200°C) and the sample cross-section area for the test standards in Australia, Europe, Japan, and United States.

CONCLUDING COMMENTS

Table 1. Comparison of CMOR results for test standards in different countries.

	Cold Modulus of Rupture		Sample Cross-Section Area
	MPa	Lbs/sq.in	mm^2
Australia	11.2	1624	8625
Europe-A	14.9	2161	7296
Europe-B	16.7	2422	3456
United States	17.7	2567	2601
Japan	20.9	3031	1600

Aachen'08 provided a good forum for the presentation and discussion of practical and technical information about refractories, along with opportunities for business and social contacts and interaction. Further details of the information presented herein, and the other presentations, can be found in the meeting Proceedings, which can be obtained from Forschungsgemeinschaft Feuerfest in Bonn, www.feuerfest-kolloquium.de or phone – 49 (0)228 915 0845. Aachen'09 is scheduled for September 23-24.

REFERENCES

1. World Steel Association, www.worldsteel.org

A DIFFERENT PERSPECTIVE

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THE ANATOMY OF A BOILER FAILURE

The power industry's operating and maintenance practices were held up to intense regulator and public scrutiny when on November 6, 2007, a Massachusetts power plant's steam-generating boiler exploded and three men died.

The Department of Public Safety's Incident Report investigation [www.mass.gov/Eeops/docs/dps/inf/salem_harbor_boiler_3_failure_nov2007_redacted.pdf] determined that the primary cause of the Dominion Energy New England's Salem Harbor Generating Station Unit 3 explosion was extensive corrosion of boiler tubes in the division wall at the east furnace lower slope dead air space (**Figure 1**). The three operators were working directly below the furnace on a pulverizer seal air fan when the explosion occurred. They died of burns and related complications. The boiler was operating at 1,900 psi at the time of the failure. A complete set of photos of the failure is included in the incident report.

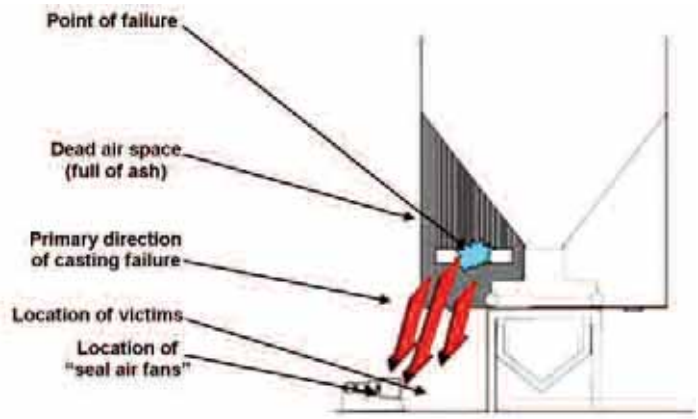

Figure 1. A tube rupture on November 6, 2007, at Dominion Energy New England's Salem Harbor Generating Station Unit 3 caused a furnace explosion that killed three men. Source: Commonwealth of Massachusetts, Department of Public Safety Incident Report: Dominion Energy New England-Salem Harbor Station Boiler #3 Failure, dated July 31, 2008.

The report concluded that when the tubes failed within the dead air space formed by the division wall—an area normally under a slight negative pressure—the vestibule was instantly pressurized, causing a secondary rupture of the boiler casing around the bottom of the furnace. Ash and 600ºF steam was then released into the area where the three workers were located (see **Figure 2**).

The report also summarized interviews with plant operations staff on standard plant operating and maintenance habits. Because the plant has operated as a cycling unit for the past ten years or so, planned outages were so reduced in length that required maintenance activities were not completed. At the time of the accident, approximately 2,500 work orders were pending.

The report also noted that the dead air space had not been opened or inspected in at least ten years and was full of ash at the time of the explosion. The report concluded that the tube explosion that blew out the outer wall of the furnace was caused by ash and water

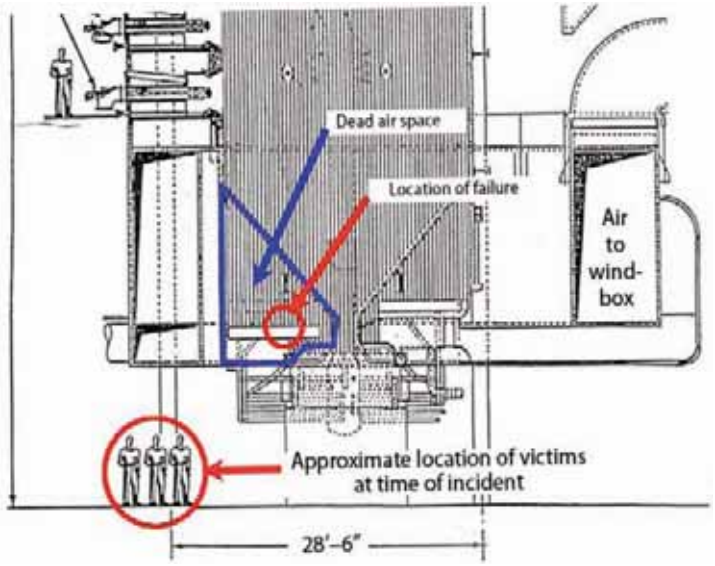

Figure 2. The Massachusetts Department of Public Safety's official Incident Report found that extensive corrosion of the boiler tubes, caused by ash captured in the lower slope air space that had mixed with water introduced by furnace washes, was the cause of the explosion. Source: Commonwealth of Massachusetts, Department of Public Safety Incident Report: Dominion Energy New England-Salem Harbor Station Boiler #3 Failure, dated July 31, 2008.

from boiler washing, coming into contact with tubes. That mixture caused corrosion that resulted in excessive tube metal loss.

The report held the chief engineer and the outside boiler inspector directly responsible for the explosion because they failed to perform a comprehensive inspection as required by Massachusetts law. In other words, the catastrophe could have been prevented if proper inspections had been made of the entire furnace and more than visual inspection techniques had been used. The Occupational Safety and Health Administration since have found ten serious safety violations at the plant, including failure to enter and inspect the area where the tube rupture occurred.

We must not close the book on this tragedy and chalk it up to bad luck on the part of this plant's staff. There is much more to the story than what is written in the Incident Report. Here is the key question that the report failed to answer: What caused the vestibule to fill up with flyash in the first place (see photos)?

I believe that the root cause of the accident was refractory failure that allowed the water and ash to enter the vestibule in the first place. A properly installed and maintained refractory surface would have prevented the corrosion and, thus, the accident.

GOOD BOILER DESIGN PRACTICE

The report states that the boiler's lower vestibule was full of flyash and had been for a very long time. Post-accident operator interviews suggest the flyash may have been there as long as ten years. Poor maintenance and inspection practices ignored this enclosed

Figure 3. Typical vestibule behind steam drum.

Figure 4. Typical upper frontwall dead air space (note fly ash).

space. Not surprisingly, this lack of attention is common throughout the power industry.

The boiler is a 1957 vintage 120-MW coal-fired radiant power boiler. This was a common boiler design for virtually all utility boilers built from the mid-1940s through the 1960s. It was not until 1964 that the membrane tube wall design was developed and became the norm in utility boiler practice. During this time period approximately 400 boilers of this design were built in the U.S., and most are still in operation. All of these boilers had similar steam capacity, tube wall construction, vestibules, and refractory/tube wall design. Does the boiler cross-section in **Figure 5** look familiar to you?

These are considered flat-studded or tangential-type boilers. They do not have membrane tube walls, but rather use either flat-studded tubes or bare loose tubes to form the boiler and furnace walls. To keep the fire (and flyash) inside the firebox, refractory is applied over the outside of the tubes to form a protective, insulating wall.

Boilers of this type used either an "all-refractory design" with refractory (1 to 2 inches thick) on the backside of the tubes or an "inner-cased design," which uses a thin layer of refractory applied flush with the backside of the tubes and a 10-gauge metal casing

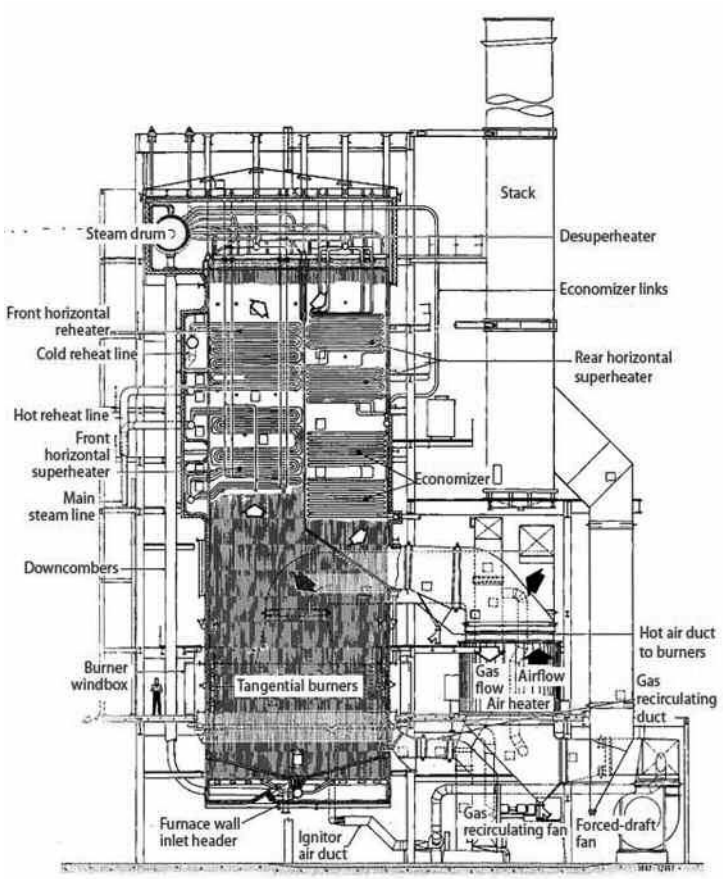

Figure 5. A typical 1957 vintage one-pass boiler that is susceptible to a failure similar to that experienced at Salem Harbor Unit 3. There are approximately 400 of these boilers in active service today. Source: BRIL inc.

installed over the refractory-backed tubes. The all-refractory design was less costly, especially in areas such as vestibules and enclosures, and was therefore the most commonly used design. For this discussion, I focus on the "all-refractory design".

In essence, the refractory must keep the fire inside the box in order to keep the boiler operating efficiently and to prevent flyash from penetrating or entering the vestibules in and around the boiler. (Please note that the following photographs were not taken at Salem Harbor Unit 3 but at units of the same boiler design and configuration.)

Figure 6. Typical refractory failure inside a lower furnace vestibule.

Figure 7. Typical refractory failure inside a lower furnace vestibule.

These vestibules and enclosures are typically located under the superheater area, above the roof tubes, under drums, around the burner area, and below or just underneath the furnace hopper slope tubes where the failure occurred.

Figure 8. Typical super heater vestibule (note expanded metal on wall).

Figure 9. Typical pulverized coal type burner inside a windbox (note expanded metal welded to tubes around burner).

The boiler designers and manufactures of these types of boilers knew that it was very important to keep flyash out of these vestibules because of the chemical constituents of flyash. Flyash is a by-product of burning coal and typically contains alkalis such as sodium and potassium that can form corrosive mixtures in the presence of water, or sulfur that can form sulfurous or sulfuric type acids, both of which can corrode or weaken structural supports and tubes in the presence of water. The photos below illustrate these points in a boiler similar to Salem Harbor Unit 3's in design and construction.

Figure 9. Typical lower furnace vestibule (note how wet the fly is).

Figure 10. Typical structural supports inside a lower vestibule.

POOR REFRACTORY PRACTICES

Boilers of this vintage and design use refractory on the backside of tubes located inside vestibules and enclosures. The refractory is approximately 1 inch thick from the face of the tube and requires a support system. In my experience, the refractory can fail for any number of reasons, including these:

- Poor refractory mixing and handling practices.
- Poor installation practices (including curing and drying).
- Improper water-washing techniques.
- Improper refractory attachment systems.

Figure 11. Typical tubes inside a lower vestibule.

Figure 13. Typical vestibule behind steam drum (note fly ash).

Figure 12. Super heater vestibule (note stain on refractory wall from water washing).

Figure 14. Typical upper frontwall dead air space (note fly ash).

The way to prevent failure is to handle, mix, and install refractory correctly and by following proper water-washing practices. What do following proper procedures mean?

▶ Proper handling means:
- Storing the refractory in a dry, well-ventilated place
- Wearing air filter masks at all times during handling of individual bags

▶ Proper mixing means:
- Using a paddle mixer, pan, or bucket, and never using a cement mixer
- Knowing the percentage or range of water required for the application the refractory is intended to be used for (i.e. trowel or pour)
- Knowing how long to mix the refractory (i.e. paddle mixing 3-4 minutes, hand mixing 5 minutes)
- knowing the expiration or manufacture date of the refractory
- knowing the pot life of the refractory (time between mixing and installing)
- Using potable (drinkable) or treated water and never river water
- Making sure that the final mix temperature is between 50-90ºF
- Never reuse or re-mix partially mixed refractory

▶ Proper installation procedures means:
- Do not over trowel the surface of the refractory
- Do not over vibrate when casting or pouring
- Cure the refractory for a minimum of 24 hours (cement bonded refractory only)
- Protect the surface for drying or crusting over for 24 hours (all types)

▶ Proper water washing procedures means:
- Avoiding areas where vestibules or enclosures are located directly behind the waterwall tubes
- Never spray directly into the refractory so as to limit or avoid washing away existing refractory materials

Unfortunately, my experience has also been that many plants have an improper refractory attachment system that is by far the most common reason for a refractory failure inside vestibules and enclosures. A refractory attachment system will support the refractory, even during boiler expansion, regardless of how the refractory is installed. (The gunning installation method uses pressure to force dry material from the charging chamber through a hose to the

Figure 15. Furnace wall with no expanded metal in some locations.

Figure 16. Insulation stud and clip used for holding expanded metal.

Figure 17. Expanded metal welded directly to tubes.

Figure 18. Nut and stud with washers holding expanded metal.

Figure 19. Expanded metal overlap is required for expansion.

point of placement; water is added at the discharge nozzle. The trowel method requires application of refractory by hand.)

Most plants pay little or no attention to the attachment system for holding refractory inside vestibule areas. The most common practices for holding expanded metal at power plants follow:

- No support system. The refractory will not last very long without a support system due to the stresses associated with boiler expansion.
- A light-gauge attachment with clips. This application uses a thin-gauge attachment with insulation-type speed clips to support the expanded metal. This design is better for supporting ceramic module insulation applications than refractory. The thin gauge of the stud and clip does not last very long when exposed to stresses associated with boiler expansion.
- Welding directly to the tubes. This approach does not allow enough support of the refractory because most of the refractory material is located above the expanded metal. Due to stresses associated with boiler expansion, expanded metal

should be placed in the middle of the refractory to give the optimum support.

- The stud and clip method. This is a good method for holding expanded metal as long as a clip is placed both under and above the expanded metal. The clip should be a heavy-duty speed clip (such as SN3) and large enough to cover the diamond shape of the expanded metal openings. The problem with this system is the difficulty of keeping the expanded metal the same distance from the tube face. The distance of the expanded metal from the tube face is critical for the success and longevity of the system.
- A hex nut and threaded stud with washers. This system is a variation of the stud and clip except that it uses hex nuts and washers for holding the expanded metal instead of a speed clip. This is a good method for holding expanded metal as long as the washers are placed both under and above the expanded metal. The heavy-duty (12-gauge minimum) washers should be large enough to cover the diamond shape of the expanded metal openings. The problem with this system is the difficulty of keeping the expanded metal the same distance from the tube face. The distance of the expanded metal from the tube face is critical for the success and longevity of this system.

A properly supported refractory should last ten years or more if the refractory is installed (and dried) correctly. All of the systems mentioned above have some drawbacks that could compromise the strength of the refractory support system and, consequently, affect refractory longevity.

Here is a method for holding 1-inch-thick refractory over the backside of tubes located inside a vestibule or enclosure that has the best chance for lasting ten years or more:

1. Weld a ½-inch carbon steel hex nut face down (not on its edge) directly to the tube face on 12-inch horizontal x 18-inch vertical for flat areas and 12-inch x 12-inch centers on sloped or overhead areas. The ½-inch nut will act as a stand-off, so the expanded metal will be located exactly in the middle of the refractory.
2. Weld 1½-inch x 9-gauge (13-gauge minimum) non-flattened expanded metal directly to the hex nut. Using this size of expanded metal will allow both the fines and course aggregate grain to penetrate through the expanded metal. Using a smaller size of expanded metal will cause a separation between the fines and course grains in the refractory. That separation reduces the strength of the refractory and will affect its longevity.
3. The expanded metal should be overlapped by 1 inch to 3 inches in all directions. This overlapping helps locate the expanded metal so welding is possible at all hex nut locations and will take up the stresses associated with boiler expansion. The expanded metal is never welded in the overlap areas.
4. Apply a medium-weight 2,000ºF minimum, 45% alumina cement-bonded refractory 1 inch over the face of tubes through the expanded metal. It takes approximately an additional ½-inch thickness of refractory to completely cover the expanded metal. Remember that using more refractory than required does not give you a stronger or better refractory application.
5. Cure the installed refractory for 24 hours by spraying/wetting the surface of the refractory with water every two hours or by spraying/painting the surface of the refractory with water-based acrylic curing and sealing compound.
6. Dry the refractory during boiler start-up by raising the boiler temperature 75ºF per hour until the water/steam temperature inside the furnace wall tubes reaches between 250ºF and 400ºF and hold it there for two hours. This will drive out the mechanical water used in the mixing process from the refractory. Then take your boiler up at 75ºF per hour to operating temperature.

LOOK TO THE FUTURE

The root cause of the tragedy in Massachusetts should have been identified as refractory failure rather than tube failure. It was the failed refractory lining that allowed flyash and water to penetrate into the lower furnace vestibule. The natural consequence of large ash deposits mixed with water and packed around boiler tubes was preventable.

The tragedy in Massachusetts would never have occurred if proper boiler inspection and maintenance practices had been followed. It is time for everyone working in or affiliated with the power industry to do their part to make sure this kind of accident will never happen again.

The industry can honor the memory of those lost by ensuring that a similar accident never occurs again by:

- Ensuring that boiler outages allow sufficient time for inspection and repair of refractory.
- Following proper procedures for handling and installing refractory.
- Paying very close attention to the refractory support system inside vestibules.
- Allowing enough time during boiler start-up procedures to dry the refractory.
- Avoiding water-washing tube walls in vestibule areas.
- Regularly inspecting vestibules and dead air spaces and quickly repairing damaged refractory.

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ST. LOUIS SECTION AND THE REFRACTORY CERAMICS DIVISION 45th ANNUAL SYMPOSIUM

The St. Louis Section and the Refractory Ceramics Division of the American Ceramic Society will sponsor the 45th annual symposium on the theme "Raw Materials" on March 25-26, 2009, held in St. Louis, Missouri at the Hilton St. Louis Airport Hotel. Co-program chairs are Bill Headrick of Missouri Refractories Co. and Dave Tucker of CE Minerals.

Listed is a schedule of papers to be presented:

"Zirconia, Its Many Types and Uses", John Kaniuk, Zircoa
"Non Standard-Standards for In House/Customer Quality Assurance and Usage", Maurice Cook, Sintertec Div of BPI, Inc.
Invited Paper the 2008 Allen Award Winner "Erosion-Corrosion-Resistant Titanium Diboride Cermets for High-Temperature Process Applications", Chang Min Chun, ExxonMobil Research & Engineering
"Develop, Analyze, and Recycle: the Service Side of Washington Mills", Brian Hauer, Washington Mills
"What Does a Refractory Company Want from a Raw Material Supplier?", Dilip Jain, Kyanite Mining
"Phosphate Bonding for Phun", George Gower, Refractory Minerals
"Refractory Raw Material Producer Challenges and the Future", Dave Tucker, CE Minerals
"Coarse Tabular Alumina Aggregates: The Next Generation of Tabular Alumina", Dale Zacherl, Almatis
"New Calcium Aluminate Binder for Low Cement Castables (LCC's)", Chuck Alt, Kerneos
"Bauxite & Brown Fused Alumina Supply in 2009", Erin Eusner, Great Lakes Minerals

An Open Panel Discussion on Raw Materials led by Charles Semler will be held on March 26th at 10:30 am.

The 2009 Theodore J. Planje Refractories Award will be presented to James W. Stendera of Vesuvius USA on March 25th at 1:00 pm.

The pre-registration fee of $225.00 or on-site registration fee of $275.00 ($125.00 for Emeritus/Seniors and $50.00 for students) includes the cost of your bound copy of the Symposium Technical Papers, Continental Breakfast, Lunch, Dinner, and Coffee Breaks.

Almatis, Aluchem, American Ceramic Society, BassTech International, Calucem, Inc., CE Minerals, Cilas Particle-Size, Electro Abrasives/USEM, Kerneos, Inc., Kyanite Mining, Great Lakes Minerals, Matrix Enterprises, Orton Ceramic Foundation, Possehl Erzkontor N.A., Refractory Minerals, Rio Tinto Alcan and Washington Mills are a partial list of Exhibitors who will be participating in the 2008 Tabletop Exposition. **We still have space available so if you are interested in participating in the Table Top Expo, contact Mary Reidmeyer at (573) 341-7519 (maryrr@mst.edu) or Patty Smith.**

A block of rooms have been set aside for the evenings of March 23-26 at the Hilton (314) 426-5500. The rate is $99.00 for a single or double. To receive the $99 rate, please refer to the St. Louis Section of the American Ceramic Society when making your reservations or you can make your reservations online at http://www.hilton.com/en/hi/groups/personalized/STLHIHF-ACS-20090323/index.jhtml. All reservations must be received on or before March 10, 2009. For further information please contact Patty Smith at Tel: (573) 341-6265, Fax: (573) 341-6151 or email: psmith@mst.edu.

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St. Louis Section
in conjunction with the
Refractory Ceramics Division

Forty-fifth Annual Symposium on Refractories

March 25-26, 2009
Hilton St. Louis Airport Hotel
Theme:

"Raw Materials"

Presenters:
Alcan, Almatis, AluChem, CE Minerals, Christy Minerals, FiberCon,
Great Lakes Minerals, Kerneos, Refractory Minerals, Sinter Tec,
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mchieppor@bnzmaterials.com

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metalcaster@unimin.com www.metalcaster.com

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Tel: (724) 857-9903 Fax: (724) 857-9917
jk@imi-minerals.com www.imi-minerals.com

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www.refractories.saint-gobain.com

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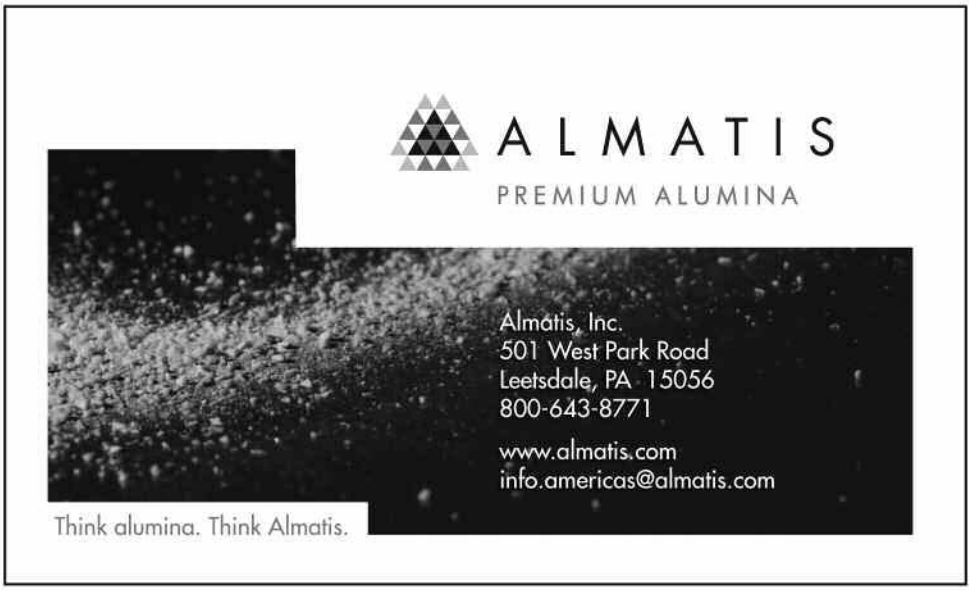

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