Thermodynamic Evaluation of the Slag System $CaO\text{-}MgO\text{-}SiO_2\text{-}Al_2O_3$

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Topics

- Introduction
- Materials and Methods
- Results and Discussion
- Conclusions

Introduction

- Knowledge of the fundamentals of steel production is very important for companies to keep their position – as the market becomes increasingly competitive.
- Consequently, there is no quality steels production without the knowledge of the slag behavior.
- Knowledge of the physico-chemical properties of the slag, such as viscosity, interfacial tension, density, basicity, thermal conductivity, among others, is essential.
- These properties, in turn, are influenced by the chemical composition and temperature of the system.

Introduction

- The oxide system CaO-MgO-SiO_2-Al_2O_3 (denoted as C-M-S-A) plays an important role in a large number of industrial processes, especially in the steel industry.
- In modern secondary steelmaking, ladle treatment has become increasingly important in the production of clean steels.
- In the case of basic ladle slag, C-M-S-A slags close to CaO/MgO saturation with moderate Al_2O_3 and SiO_2 contents are used.

Introduction

- Figure 1 shows the pseudo-ternary CaO-MgO-SiO_2 diagram with a fixed 20 wt.% Al_2O_3 content from SLAG ATLAS.

- A series of dotted lines in the liquid surfaces of this diagram denote a quantity of data uncertainties.

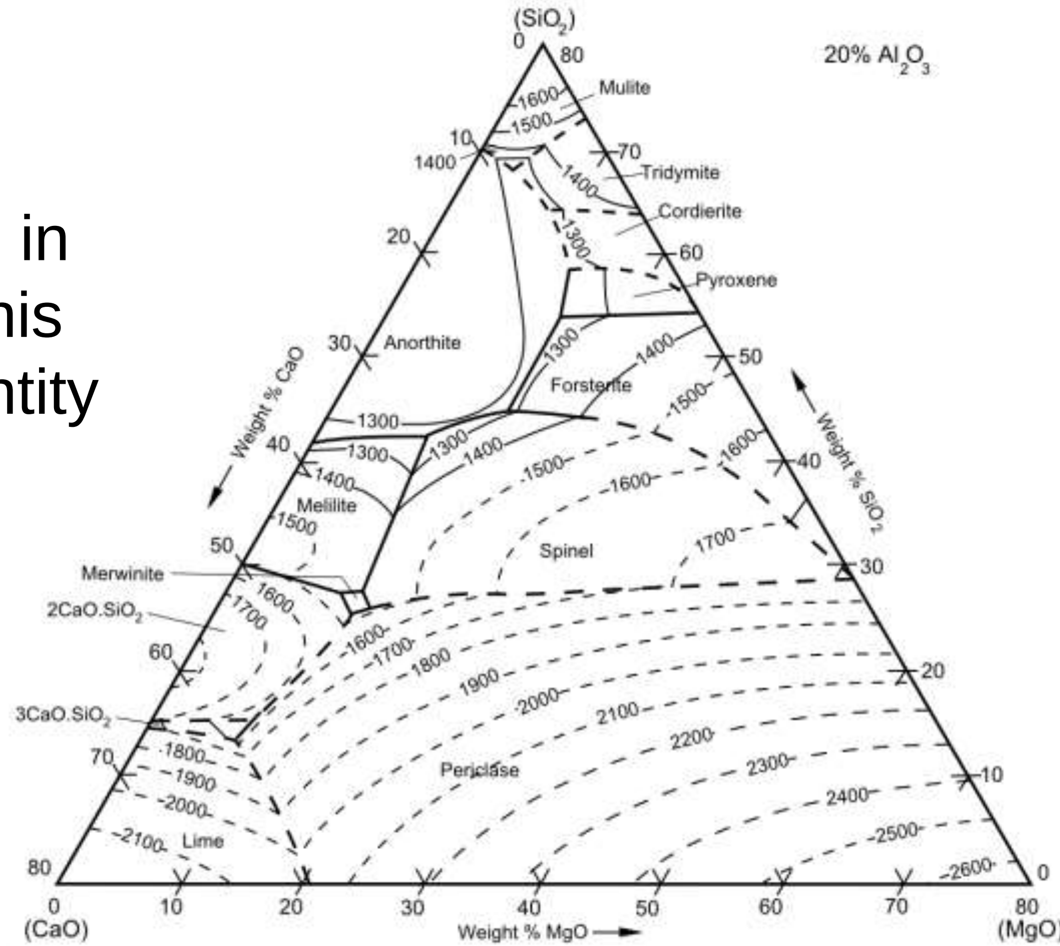

Figure 1. C-M-S-A at 20 wt.% Al_2O_3.

Goals

(1) To perform a thermodynamic study of the phases at equilibrium at a high basicity value (binary basicity, B_2, equal to 2) in C-M-S-A slags.

(2) To evaluate the slag viscosity values (checking results obtained *via* thermodynamic software with data coming from the literature) as a function of the slag composition and temperature, establishing therefore a critical analysis.

Materials and Methods

- The focused oxide systems is a pseudo-ternary system CaO-MgO-SiO_2 with fixed levels of Al_2O_3
- The thermodynamic approach was executed with the help of the computational thermodynamic software FactSage 6.3 (Equilibrium module) using FToxid sub-systems.
- The thermodynamic simulations were performed under the following conditions:

✓ wt.% CaO / wt.% SiO_2 mass ratio (binary basicity, B_2) kept constant (generally B_2 = 2) for any MgO content;

✓ fixed amount of 20 wt.% Al_2O_3 for all simulations;

✓ constant total mass of 100 g;

✓ temperatures of 1,500°C; 1,550°C; 1,600°C.

Results and Discussion

Phases and Phase Diagrams

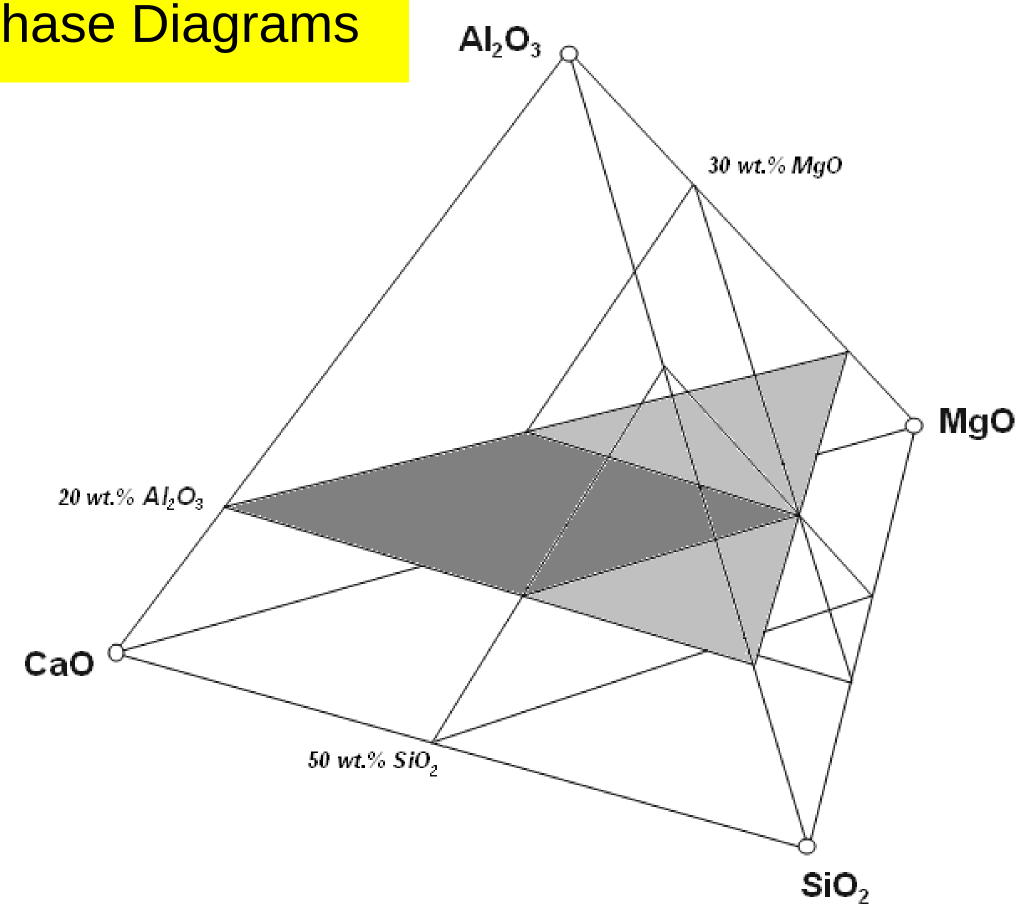

Figure 2. Schematic diagram of the quaternary system C-M-S-A indicating the *plane* at 20 wt.% Al_2O_3 (light gray) and the area used to plot the phase equilibrium diagrams (dark gray) which illustrate this work (*not to scale*).

Results and Discussion

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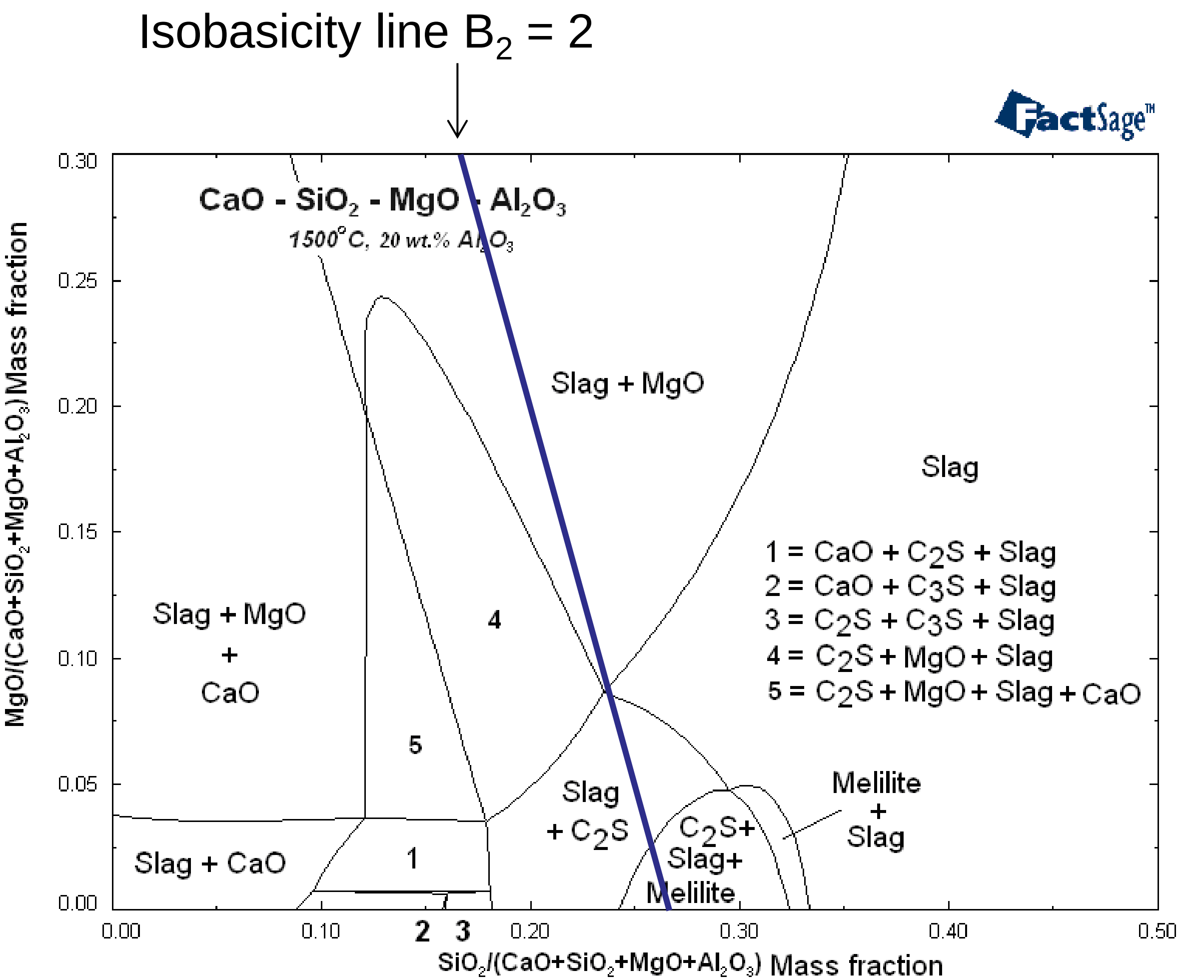

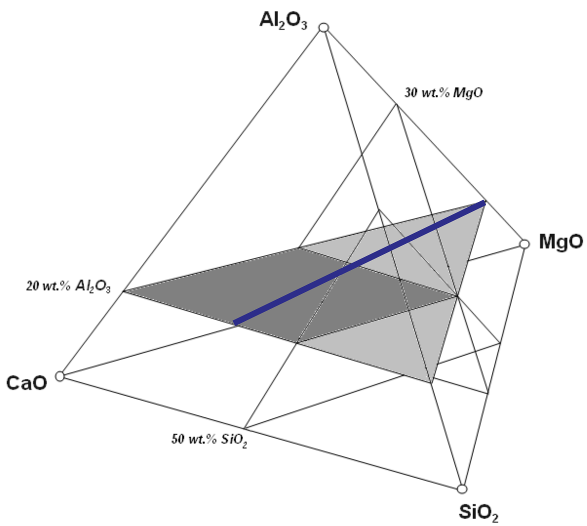

Figure 3. CaO-MgO-SiO_2 pseudo-ternary phase diagram depicting the CaO-rich corner (C-M-S-A system at 20 wt.% Al_2O_3) at the temperature of 1,500°C.

Results and Discussion

Isobasicity line $B_2 = 2$

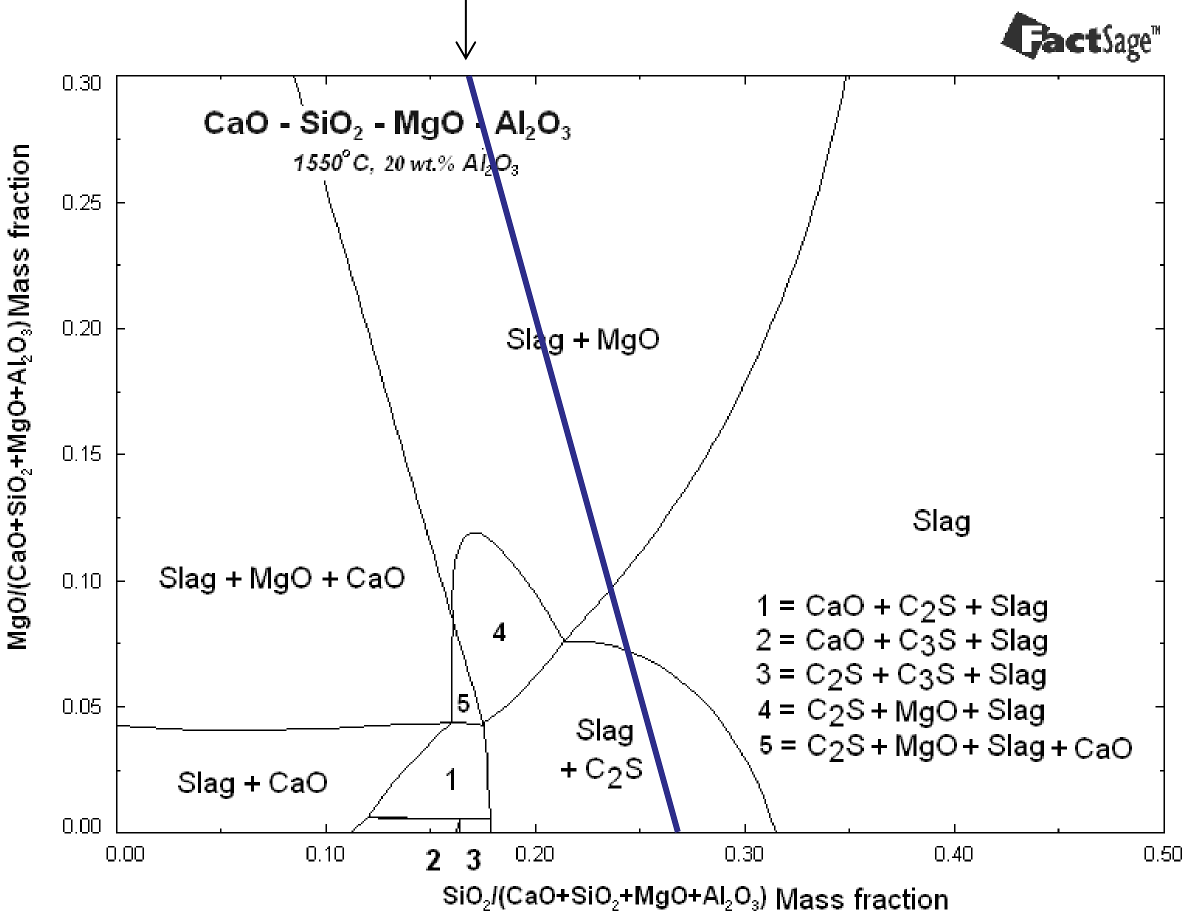

Figure 4. CaO-MgO-SiO_2 pseudo-ternary phase diagram depicting the CaO-rich corner (C-M-S-A system at 20 wt.% Al_2O_3) at the temperature of 1,550°C.

Results and Discussion

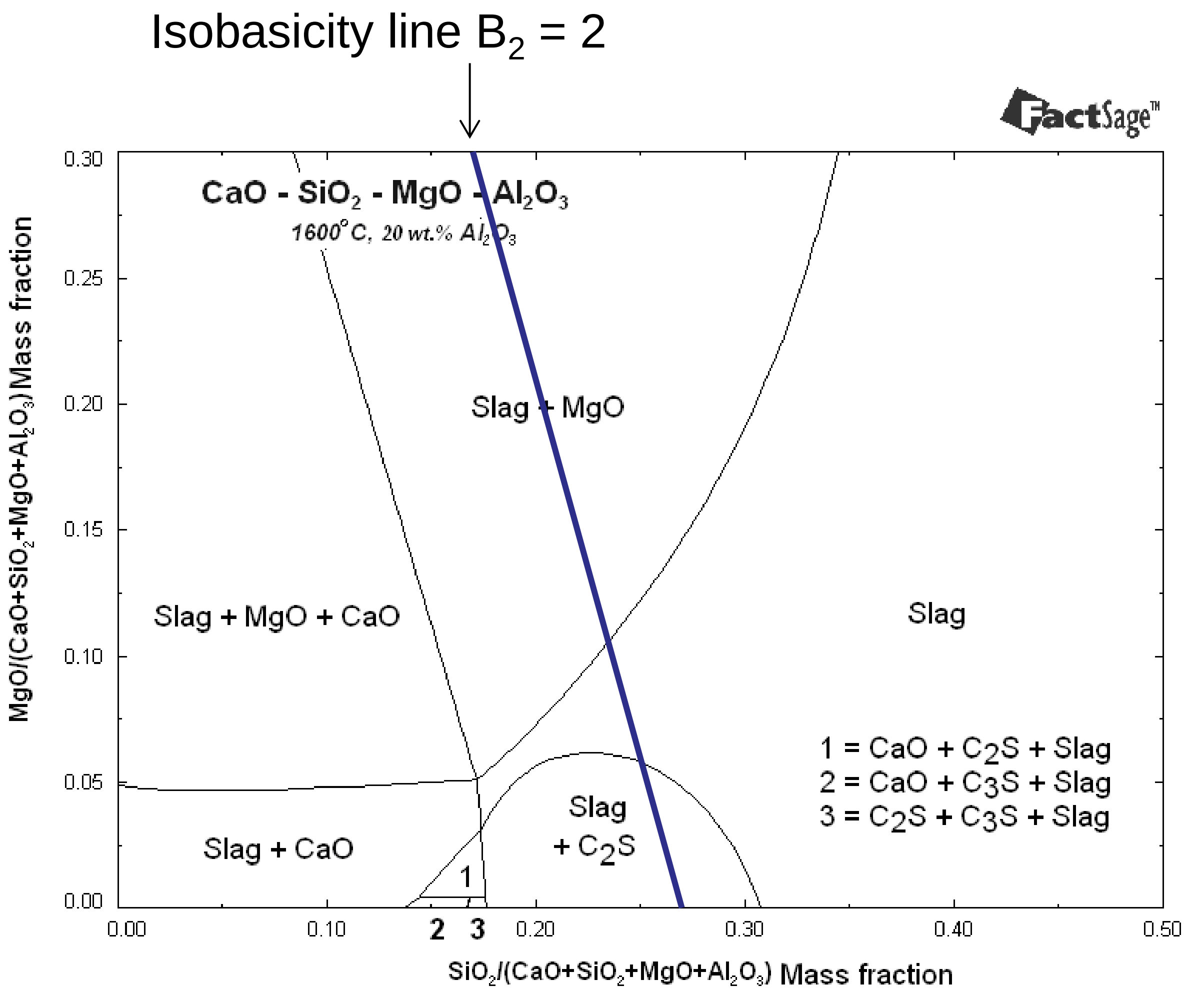

Figure 5. CaO-MgO-SiO_2 pseudo-ternary phase diagram depicting the CaO-rich corner (C-M-S-A system at 20 wt.% Al_2O_3) at the temperature of 1,600°C.

Results and Discussion

Phase Amount for Binary Basicity B_2 Equal to 2

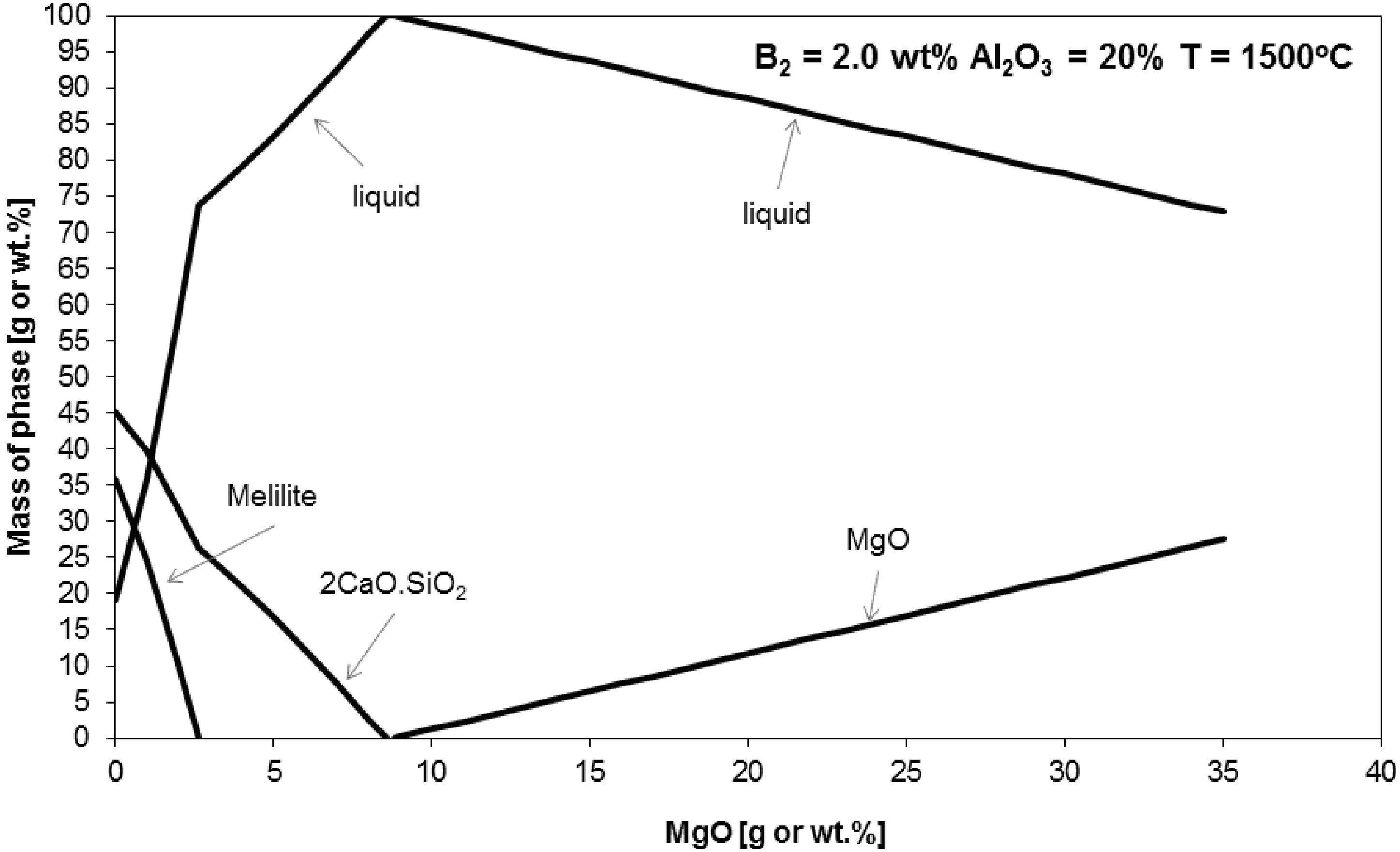

Figure 6. Mass of phases in the equilibrium state for wt.%CaO/wt.%SiO_2 = 2, Al_2O_3 = 20 wt.% and variable amount of MgO (0 to 35 wt.%); T = 1,500ºC; FactSage.

Results and Discussion

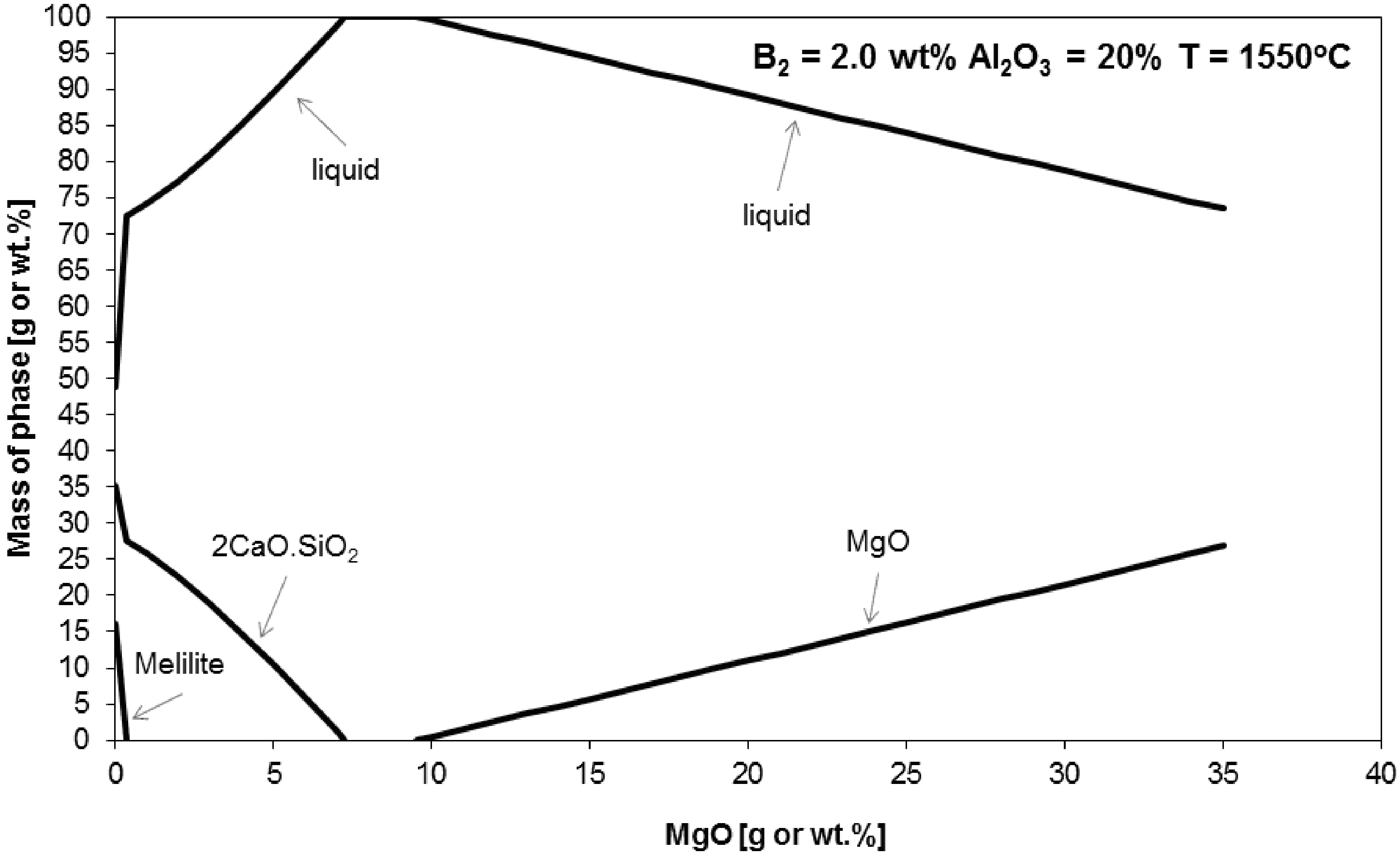

Figure 7. Mass of phases in the equilibrium state for wt.%CaO/wt.%SiO_2 = 2, Al_2O_3 = 20 wt.% and variable amount of MgO (0 to 35 wt.%); T = 1,550°C; FactSage.

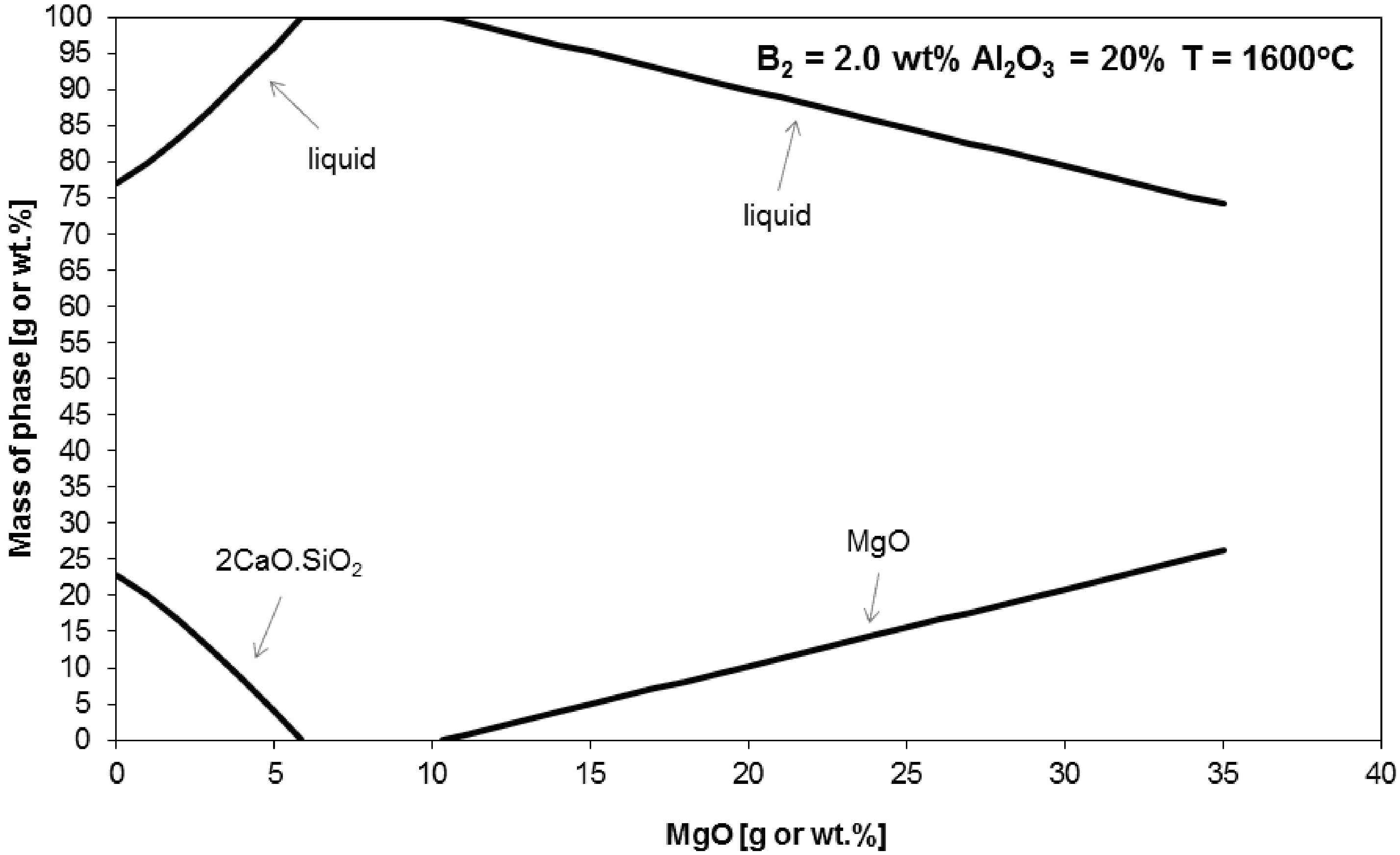

Figure 8. Mass of phases in the equilibrium state for wt.%CaO/wt.%SiO_2 = 2, Al_2O_3 = 20 wt.% and variable amount of MgO (0 to 35 wt.%); T = 1,600°C; FactSage.

Results and Discussion

C-M-S-A system at 20 wt.% Al_2O_3
Isothermal section at T = 1,600ºC

$B_2 = 2$

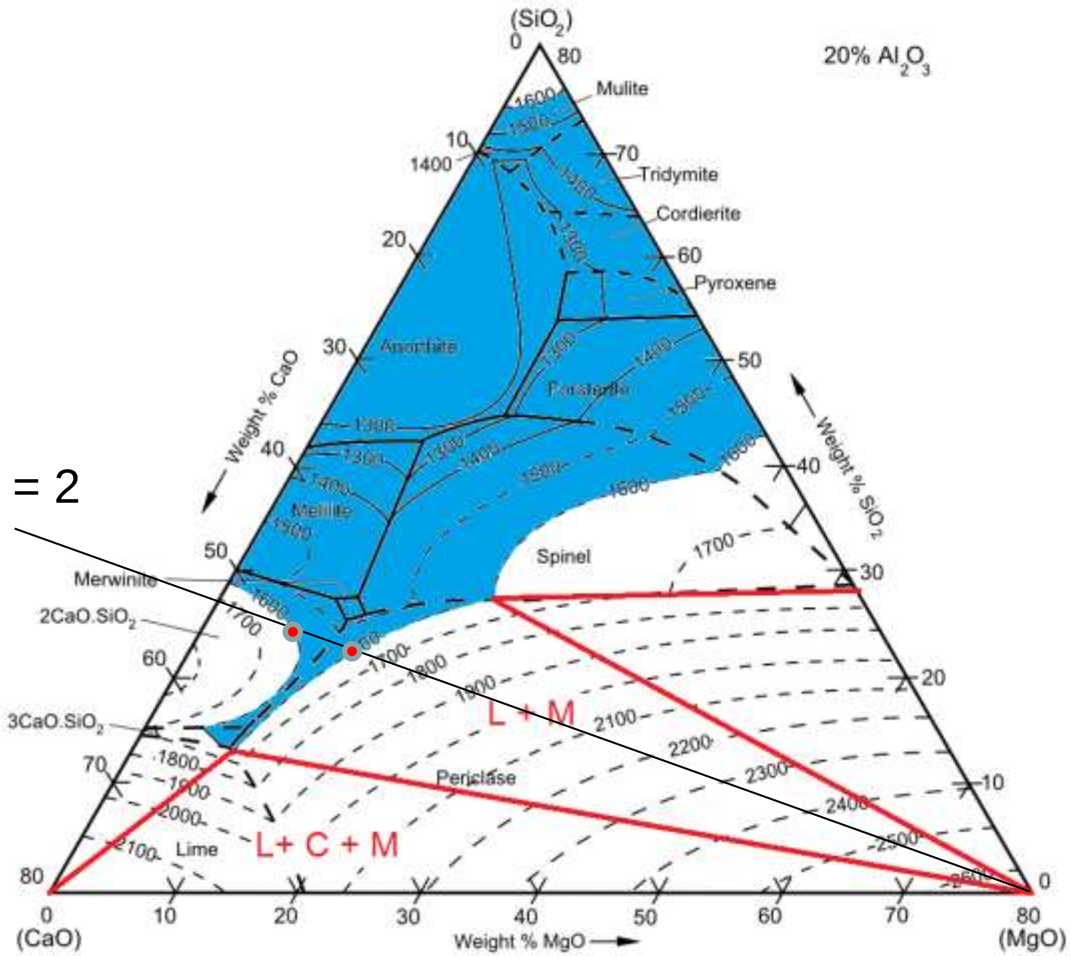

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Table 1. Comparison of MgO wt.% values between Slag Atlas data (C-M-S-A system at 20 wt.% Al_2O_3) and simulation results (FactSage) to wt.%CaO/wt.%SiO_2 = 2.

	Slag Atlas CMSA phase diagram (20 wt.% Al_2O_3)			FactSage		
	1500 ºC	1550 ºC	1600 ºC	1500 ºC	1550 ºC	1600 ºC
100% Liquid	*	9.5	8.0	8.6	7.3	5.9
Periclase saturation	*	11.9	12.7	8.8	9.5	10.3
Δ wt.% MgO	-	2.4	4.7	0.2	2.2	4.4

* B_2 isobasicity line equal to 2 does not cross the *Liquid* slag phase field.

Results and Discussion

Pure Liquid Slag Viscosity

The viscosity of the pure Liquid slag was calculated *via* FactSage (using *melts* database).

Table 2. Viscosity (Poise) values comparison between Slag Atlas data and simulation results (FactSage),
(C-M-S-A system at 10 wt.% MgO and 20 wt.% Al_2O_3, variable 35-50 wt.% SiO_2).

	wt.% SiO_2				
	35	40	45	50	T [ºC]
Slag Atlas	4	7	11	22	1500
FactSage	3.1	4.9	8.9	19.0	1500
	2.4	3.6	6.4	13.2	1550
	1.8	2.8	4.7	9.3	1600

Results and Discussion

Solid-Liquid Slag Viscosity

- Most slag models are conceived for fully molten slags since their theoretical basis is not applicable to solid–liquid mixtures.

- The presence of solid phases in the slag will affect viscosity in two ways.

First, the components which form the solids are no longer part of the liquid phase. This changes the liquid phase composition and hence its viscosity.

Second, the interaction of solid particles with each other and the liquid phase will affect the bulk slag viscosity. This effect will vary with the size, shape, orientation and mass fraction of the particles.

Results and Discussion

- Pretorius e Carlisle provided the concept of *effective viscosity*, which was defined to relate viscosity to the amount of second phase particles. It is based of Roscoe-Einstein model, as follows:

$$\eta_e = \eta\left(1 - 1.35\Theta\right)^{-5/2}$$

were:

η_e effective viscosity of the Slag

η viscosity of the molten (Liquid) Slag

Θ fraction of precipitated solid phases

Results and Discussion

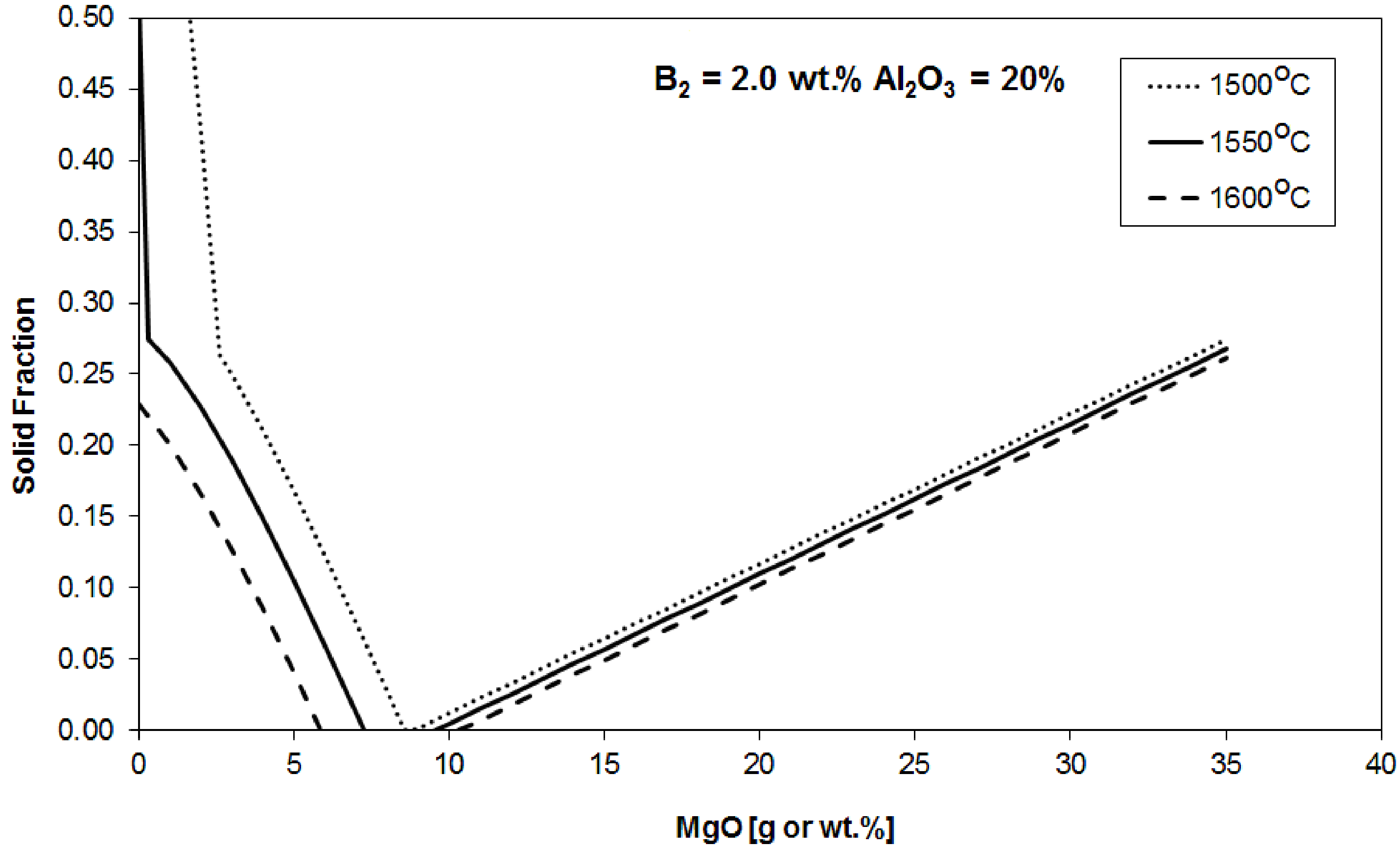

Figure 9. Solid fraction for slags in Figures 6 to 8 at 1,500°C, 1,550°C and 1,600°C.

Results and Discussion

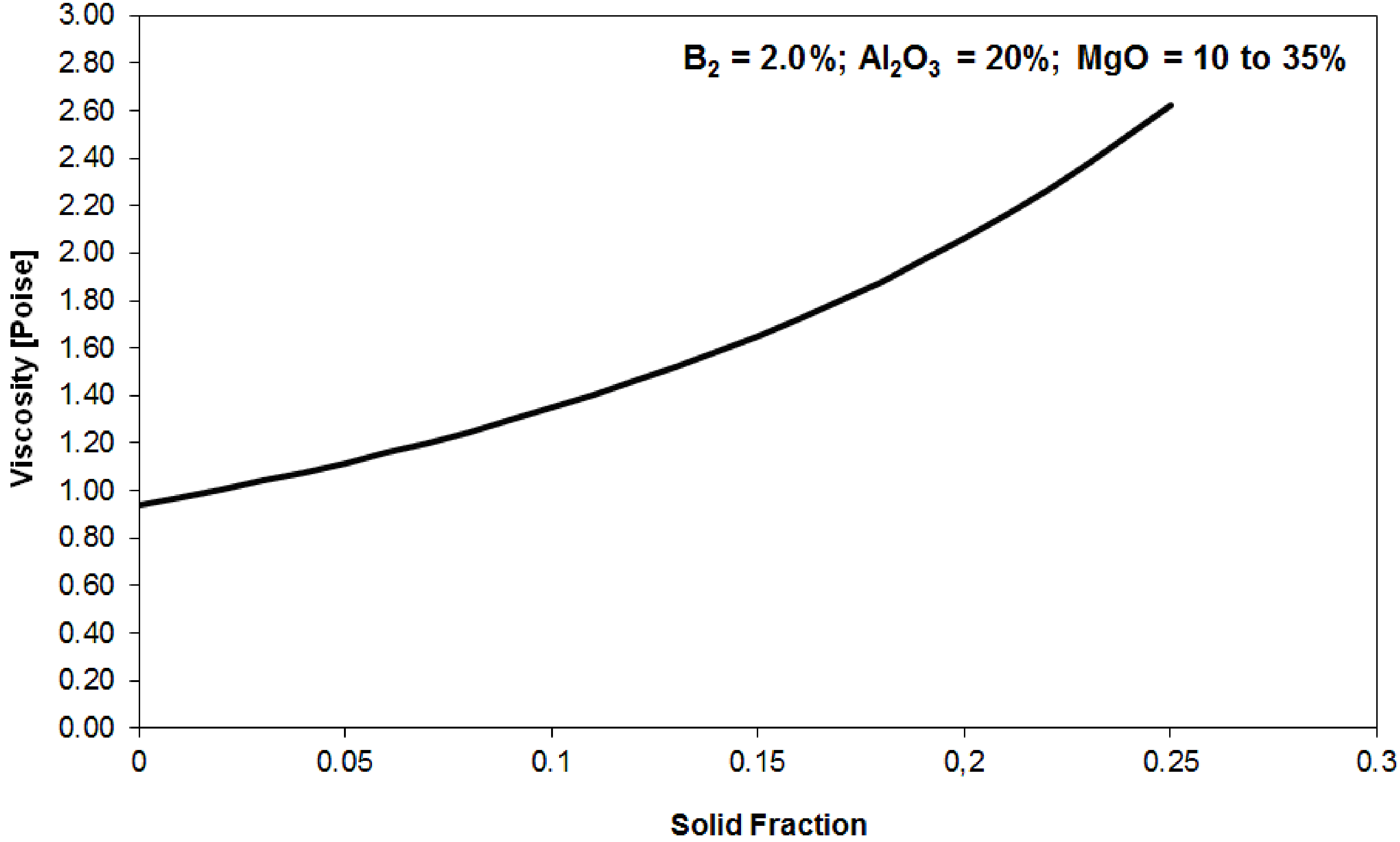

Figure 10. Effective viscosity determined for the Liquid Slag: 10.3 wt.% MgO; 20 wt.% Al_2O_3; 46.5 wt.% CaO e 23.3 wt.% SiO_2 at 1,600ºC.

General Conclusions

- Comparing the line for the 1600ºC isotherm in Figure 1 (C-M-S-A system at 20 wt.% Al_2O_3) with that of corresponding phase diagram from FactSage, it can be said that there is an acceptable similarity between them.
- However, it can be noted also that MgO content for some Periclase saturation points determined with the help of FactSage software, in comparison with Slag Atlas data, are somewhat smaller.
- The Slag Atlas does not give viscosity values for slags of binary basicity equal to 2; nevertheless, for some compositions at 1,500ºC, it shows some consistencies with FactSage calculated values for the C-M-S-A system.

THANK YOU!!

QUESTIONS?

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