Slag Viscosity Calculation of the CaO-SiO_2-Al_2O_3-MgO System Using the FactSage 6.4

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Introduction

The study of molten slag properties has become increasingly important within the steel industry, with its primary objective to increase productivity, produce a higher quality product and reduce process costs.

Among the features of this slag is viscosity due to its fundamental importance in the process.

Unfortunately, slag viscosity study is highly problematic, measurements are difficult, expensive and often carry considerable errors, according to Mills et al [1], and uncertainties around 25 to 30% are expected.

Introduction

Over the years, several mathematical models about viscosity have been developed and some remain in use.

As all models are based on data obtained experimentally, it can be expected that the values calculated from these had the same level of uncertainty as the data on which they were based.

Thus, in a sufficiently large number of calculations, the difference between calculated and measured data should be around 25 to 30%.

Goals

The objective is, by comparing the data calculated by the software and those obtained in published studies, to analyze the efficiency of viscosity calculation model of the FactSage software (version 6.4), currently available in the market, and that has been used by Steel Laboratory of UFRGS, for a range of compositions in the CaO-SiO_2-Al_2O_3-MgO system.

Materials and Methods

In order to verify the efficiency / behaviour of the FactSage program for the viscosity calculation, version 6.4 was used.

Data from the literature [3-11] obtained experimentally were compared to calculated values by the software.

All data were measured using a rotational or vibrating viscometer in the molten slag sample and they cover a wide range of compositions in the CaO-SiO_2-Al_2O_3-MgO system.

Materials and Methods

Machin et al [6,7] have studied the viscosity of a large amount of compositions, mainly focusing on the role of alumina.

Forsbacka et al [3] focused on iron-chromium production slag.

Kim et al [5], Nakamoto et al [8] and Tang et al [10] emphasized on blast furnace slag.

Jönsson et al [4], Yakushev et al [11] and Song et al [9] on secondary refining slag from steel.

Materials and Methods

Table 1 - Distribution of the slag composition [6,7].

	Al_2O_3 (% in mass)	CaO (% in mass)	SiO_2 (% in mass)	MgO (% in mass)	%CaO/%SiO_2
Maximum	25	40	50	30	0.8
Minimum	5	5	50	0	0.1

Table 2 - Distribution of the iron-chromium slag composition [3].

	Al_2O_3 (% in mass)	CaO (% in mass)	SiO_2 (% in mass)	MgO (% in mass)	%CaO/%SiO_2
Maximum	30	20	40	38	0.8
Minimum	25	2	25	20	0.05

Table 3 - Distribution of the blast furnace slag composition [5,8,10].

	Al_2O_3 (% in mass)	CaO (% in mass)	SiO_2 (% in mass)	MgO (% in mass)	%CaO/%SiO_2
Maximum	35	52.7	59.38	10	7.12
Minimum	0	25	7.4	4.9	0.5

Table 4 - Distribution of the steel slag secondary refining composition [4,9,11].

	Al_2O_3 (% in mass)	CaO (% in mass)	SiO_2 (% in mass)	MgO (% in mass)	%CaO/%SiO_2
Maximum	40	58	45.5	12	5.5
Minimum	0	39	10	0	1.19

Materials and Methods

The authors’ choice was made as to explore a wide range of viscosities, ranging from 0.1 Pa.s to 16,300 Pa.s, thereby allowing complete verification of the software’s capabilities.

The presence of solids in the molten slag was not considered, the resulting data is provided directly by the software, without further treatment.

For the calculations, FactSage Viscosity module was used. This uses a Quasi-Chemical model and software database to calculate the viscosity of the oxide system. The database used was Melts, which according to software documentation [12], is suitable for viscosities up to e^{15} Pa.s.

Results and Discussion

Image 1 shows the comparison between the values found in literature and those calculated by FactSage 6.4.

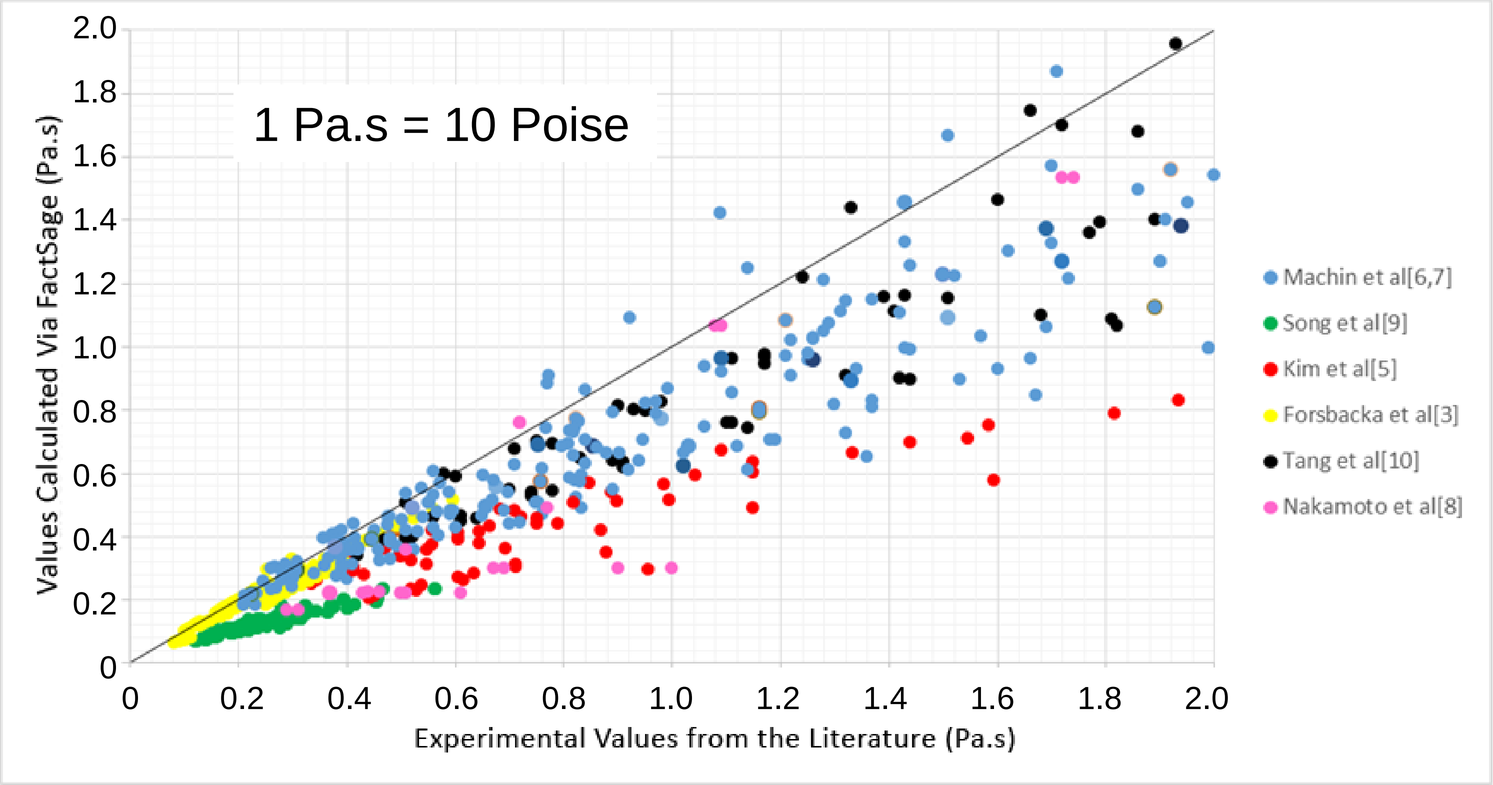


Image 1 - Viscosity values calculated vs. experimental values in literature.

Results and Discussion

Image 1 shows that the dots are dispersed in the graph, indicating a non-linearity in the ratio between the values, especially in data of Machin et al [6,7] (blue dots) for values above 0.5 Pa.s.

The values calculated in the usual compositions for slag show a strong trend to be lower than those measured in the aforementioned studies.

Data of Forsbacka et al [4] and Song et al [9] were those that showed greater linearity, while the first, Forsbacka et al [4], showed less variation between the measured and calculated values.

Results and Discussion

Table 5 shows the absolute value of the average, composed by the percentage difference between the measured and calculated values by FactSage for each studied point.

This number shows the distance between these values, as expressed by equation 1, proposed by Mills et al [1] and Forsbacka et al [3].

It notes that the use of the module in the numerator of the equation masks the trend of the calculated values are lower, but shows the difference properly and it is important for a direct comparison with the work of the cited authors.

$$\boxed{\delta_n = \frac{|(\eta_n)_{cal} - (\eta_n)_{med}|}{(\eta_n)_{med}} \, x\,100 \quad (1)}$$

Whereas:

δ_n – *Absolute value of the average*

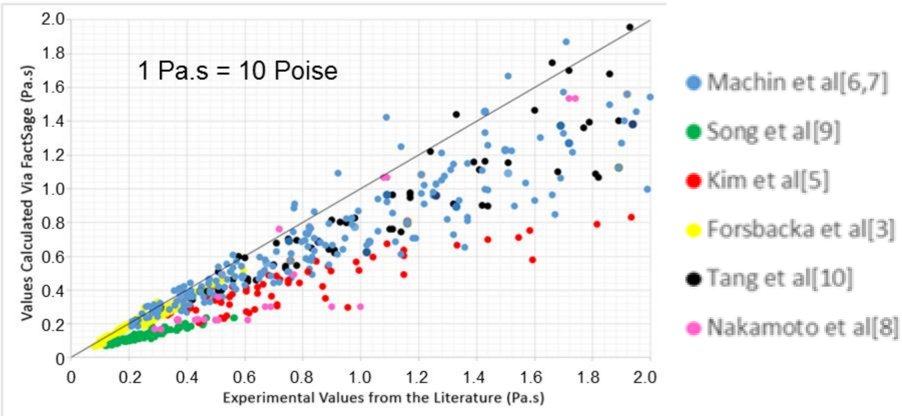
$(\eta_n)_{cal}$ – *Average of calculated values*

$(\eta_n)_{med}$ – *Average of values from the literature*

Results and Discussion

Table 5 - Difference between calculated and measured viscosity values.

	Song et al[9]	Machin et al[6]	Machin et al[7]	Kim et al[5]	Forsbacka et al[3]	Nakamoto et al[8]	Tang et al[10]
δ Average (%)	48.29	31.83	24.03	44.81	13.21	36.62	25.63
Standard Deviation	6.02	19.50	15.06	13.19	6.94	22.44	17.33
δ Max. (%)	60.83	107.67	71.95	72.06	27.68	69.90	83.98
δ Min. (%)	24.89	0.36	0.35	20.42	1.25	1.20	0.40



In general, the software provided adequate accuracy, as proposed by Mills et al [1], whereas the average distance between all the calculated and measured values was 32.06%.

Results and Discussion

Image 2 - Calculated and measured viscosities for slag studied by Jönsson et al [4].

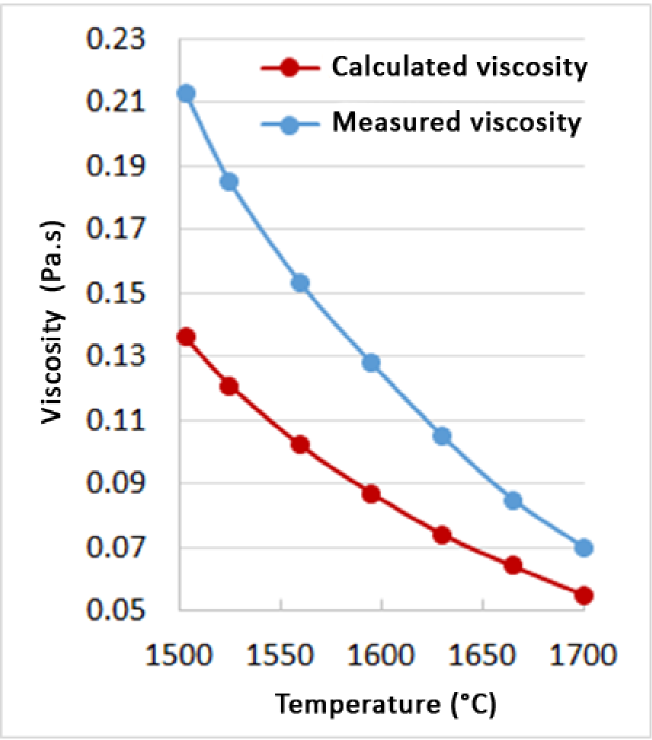


Table 6 - Chemical composition of the slag studied by Jönsson et al l[4].
(% in mass)

Al_2O_3	CaO	SiO_2	MgO	CaO/SiO_2
30	50	13	7	3.85

Results and Discussion

Image 3 - Viscosities calculated from the data from Yakushev et al[11], varying in a) MgO or Al_2O_3; b) SiO_2; c) CaO.

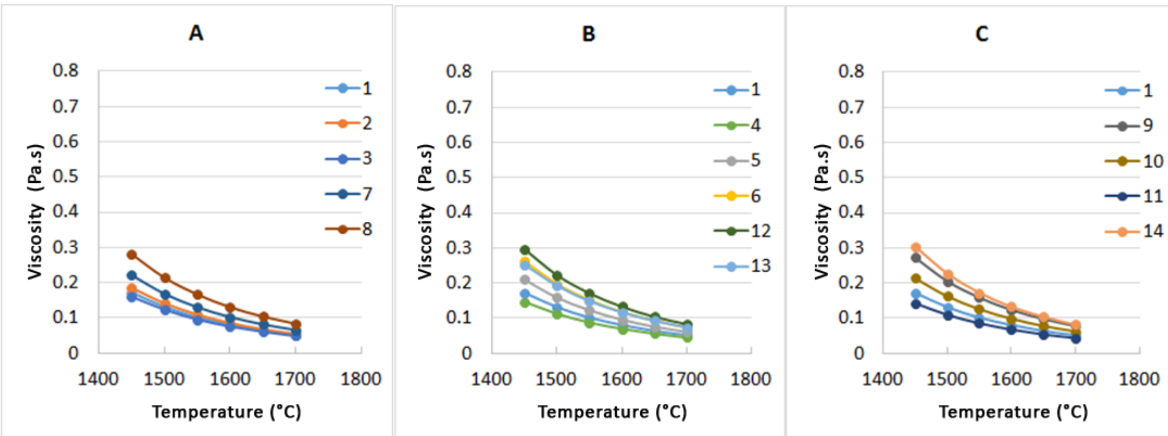


Image 4 - Viscosities measured, varying in a) MgO or Al_2O_3; b) SiO_2; c) CaO.
Source: Adapted from Yakushev et al[11].

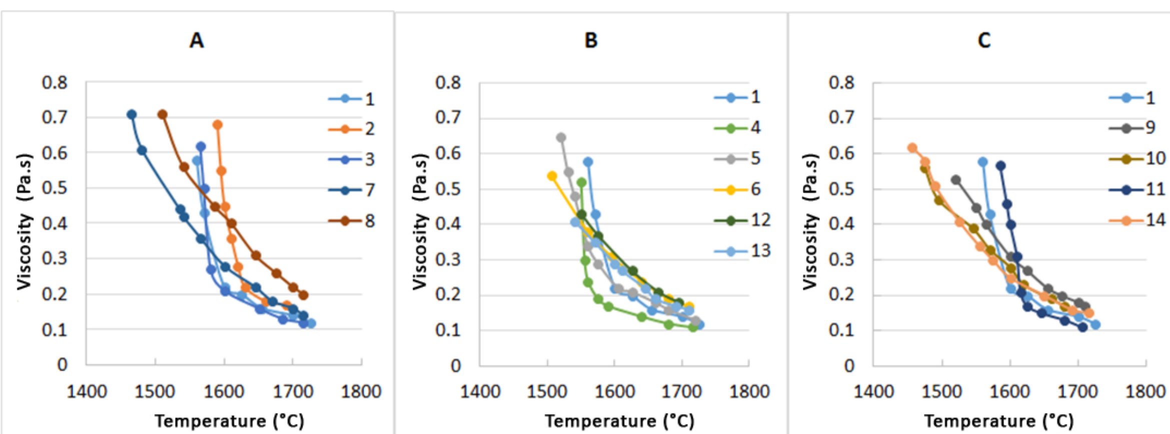


Table 7 - (% in mass)

A	Variation of MgO or Al_2O_3				
	Al_2O_3	CaO	SiO_2	MgO	CaO/SiO_2
1	20	52	20	8	2.60
2	20.9	54.2	20.9	4	2.59
3	19.1	49.8	19.1	12	2.61
7	30	45.5	17.5	7	2.60
8	40	39	15	6	2.60

B	Variation of SiO_2				
	Al_2O_3	CaO	SiO_2	MgO	CaO/SiO_2
1	20	52	20	8	2.60
4	21.2	55.3	15	8.5	3.69
5	18.75	48.75	25	7.5	1.95
6	17.5	45.5	30	7	1.52
12	20	42	30	8	1.40
13	30	42	20	8	2.10

C	Variation of CaO				
	Al_2O_3	CaO	SiO_2	MgO	CaO/SiO_2
1	20	52	20	8	2.60
9	25	40	25	10	1.60
10	22.5	46	22.5	9	2.04
11	17.5	58	17.5	7	3.31
14	0	54.5	45.5	0	1.20

Results and Discussion

Usually, temperature increase causes a decrease in viscosity values in an almost quadratic form, with a quite smooth curve.

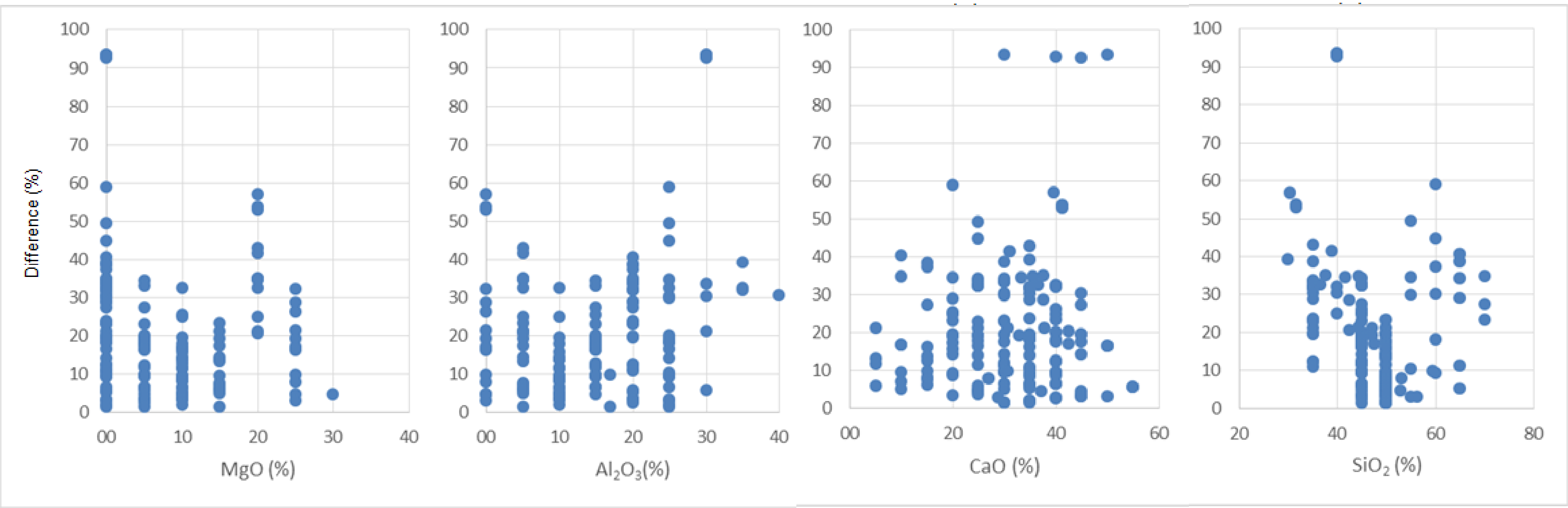
Such behavior is observed in the temperature where the influence of the solid phase present in the slag is small in this case, temperatures up to 1600ºC, and the highest temperatures are 1630ºC liquidus in the slag 2 and 11.

The data analyzed was not observed this behavior, because the curves behave erratically even above liquidus temperature, making these low credibility.

This statement is consistent with Duchesne et al [13], where the validity and accuracy of such measurements is questionable.

Results and Discussion

Image 5 - Difference between the values (δ_n) vs. component fraction in:
a) MgO; b) Al_2O_3; c) CaO; d) SiO_2



(a) (b) (c) (d)

The distribution of points is random, not showing any relationship between the values (δ_n) and the fraction of any slag component.

Thus it can be inferred that the model used by FactSage 6.4 is not biased regarding any of the 4 elements that were targeted in this study.

It is also possible to show that most of the points are in the region below 40% of uncertainty, as had been shown through the averages in Table 5.

Conclusions

It was analyzed 972 slag in the CaO-SiO_2-Al_2O_3-MgO system, varying composition and temperature, using the FactSage 6.4 software.

The software has a great trend to provide results with viscosities lower than those experimentally measured.

The average distance between all the calculated and measured values was 32.06% and it proved to be suitable within the broad range of analyzed and expected compositions, according to the literature.

There was no direct relationship between the software's efficiency and the fraction of any element present in the slag.

References

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THANK YOU!!

QUESTIONS?

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