ISO-VISCOSITY CURVES FOR CaO-SiO_2-Al_2O_3-MgO STEELMAKING SLAGS AT 1500ºC

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INTRODUCTION

- Why study the viscous behavior of the steelmaking slags?

Viscous behavior

Physical-chemical properties

- Gas permeability
- Heat transfer
- Reduction of FeO
- Rate of desulphurization

For these reasons

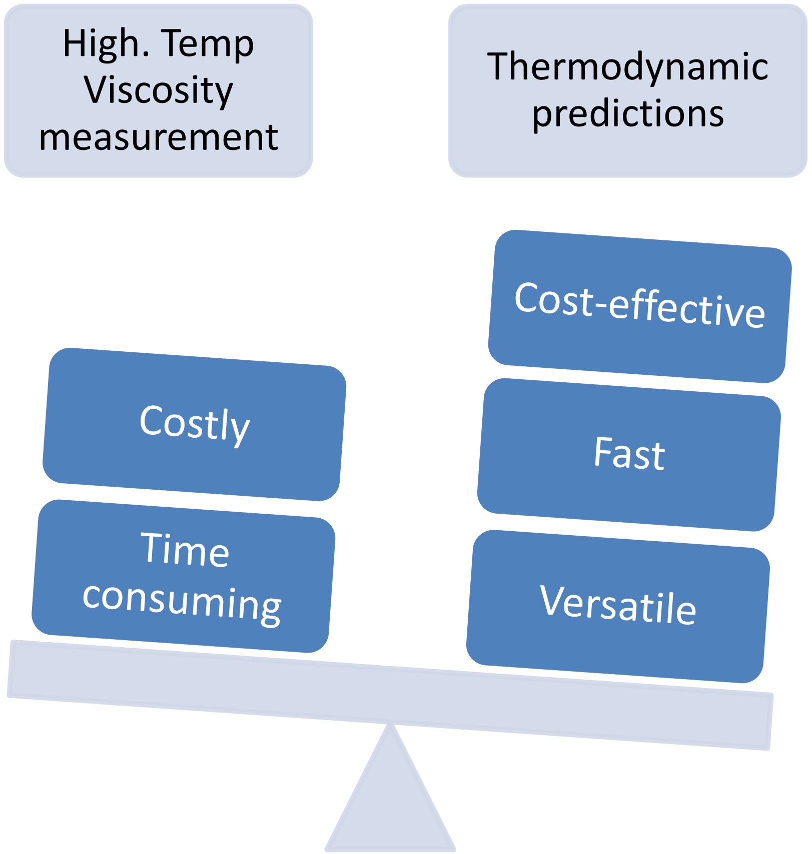
For more than six decades the slag viscosities are studied

- Theoretical research
- Industrial application

To improve the steel cleanliness

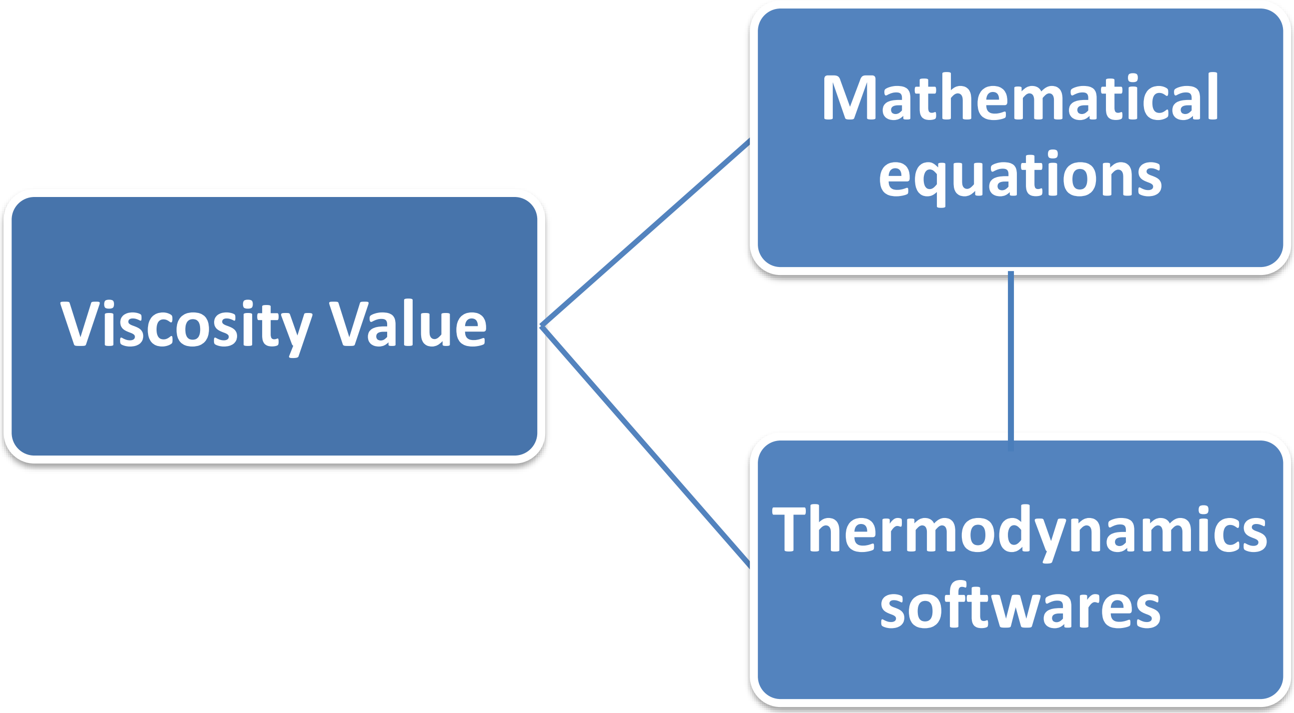
INTRODUCTION

- **Viscosity**
  - Chemical composition
  - Temperature
  - Fraction Liquid/Solid



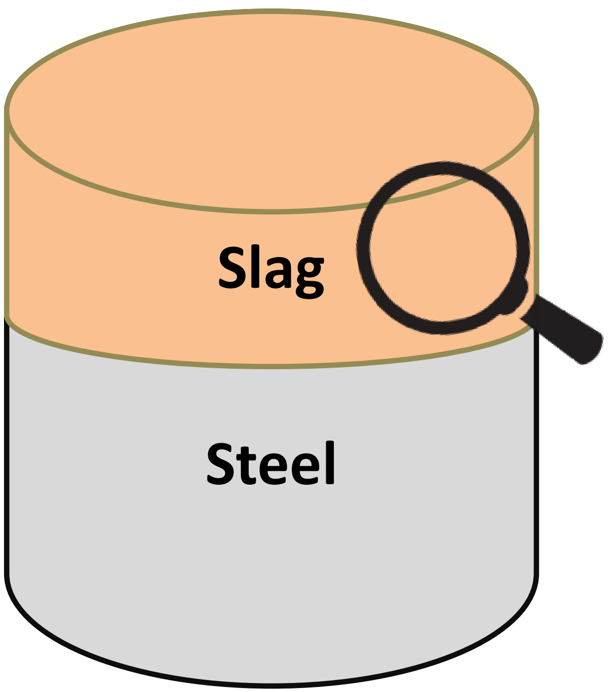
INTRODUCTION

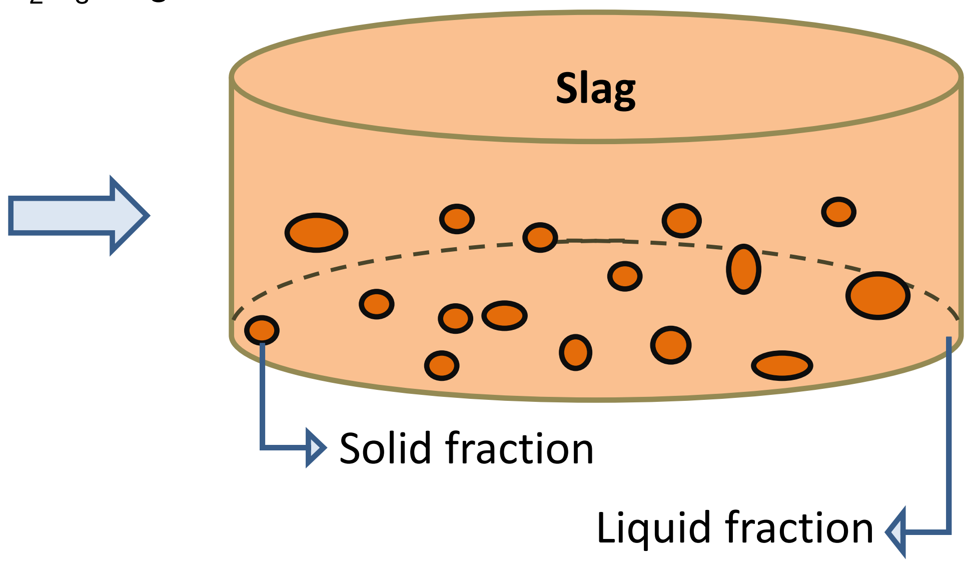
- For thermodynamic predictions it is possible to apply mathematical models or thermodynamic softwares to obtain viscosities for a given range of chemical composition and temperature of slags.



INTRODUCTION

- As known, steelmaking slags in high temperatures presents two-phase melt, Phase Mixture, in which it contains a liquid fraction and a solid fraction.
- The steelmaking slags, at secondary refining, conventionally contains CaO, SiO_2, Al_2O_3, MgO, (CSAM System);

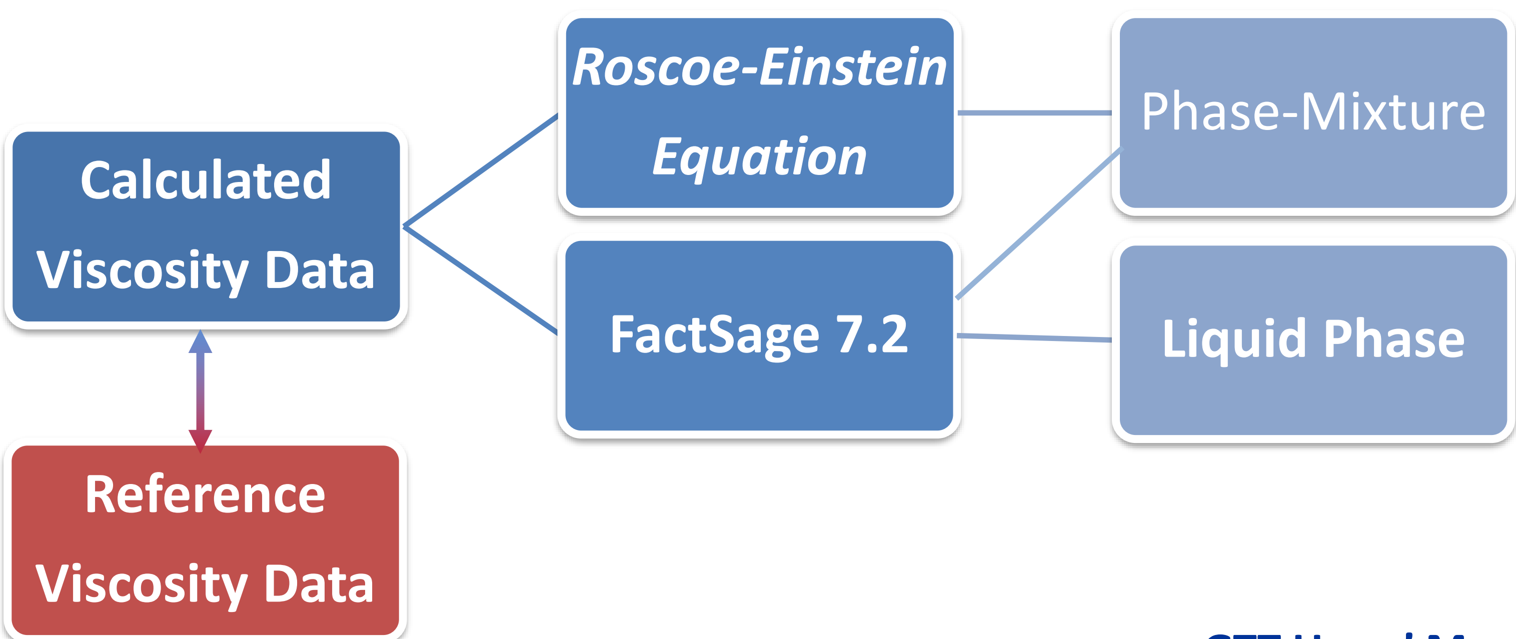




Solid particles hamper the viscosity measurements in the Phase Mixture.

INTRODUCTION

- The aim of the present work is to apply a mathematical model and thermodynamic software, ***FactSage 7.2***, to the Phase Mixture and thermodynamic software to the Liquid Phase, ***FactSage 7.2***, to obtain the slags viscosities in CSAM system, for a given temperature of 1500ºC and within a range of chemical composition of slags.
- And calculate the convergence of the experimental data, collected in the literature, with a calculated data.



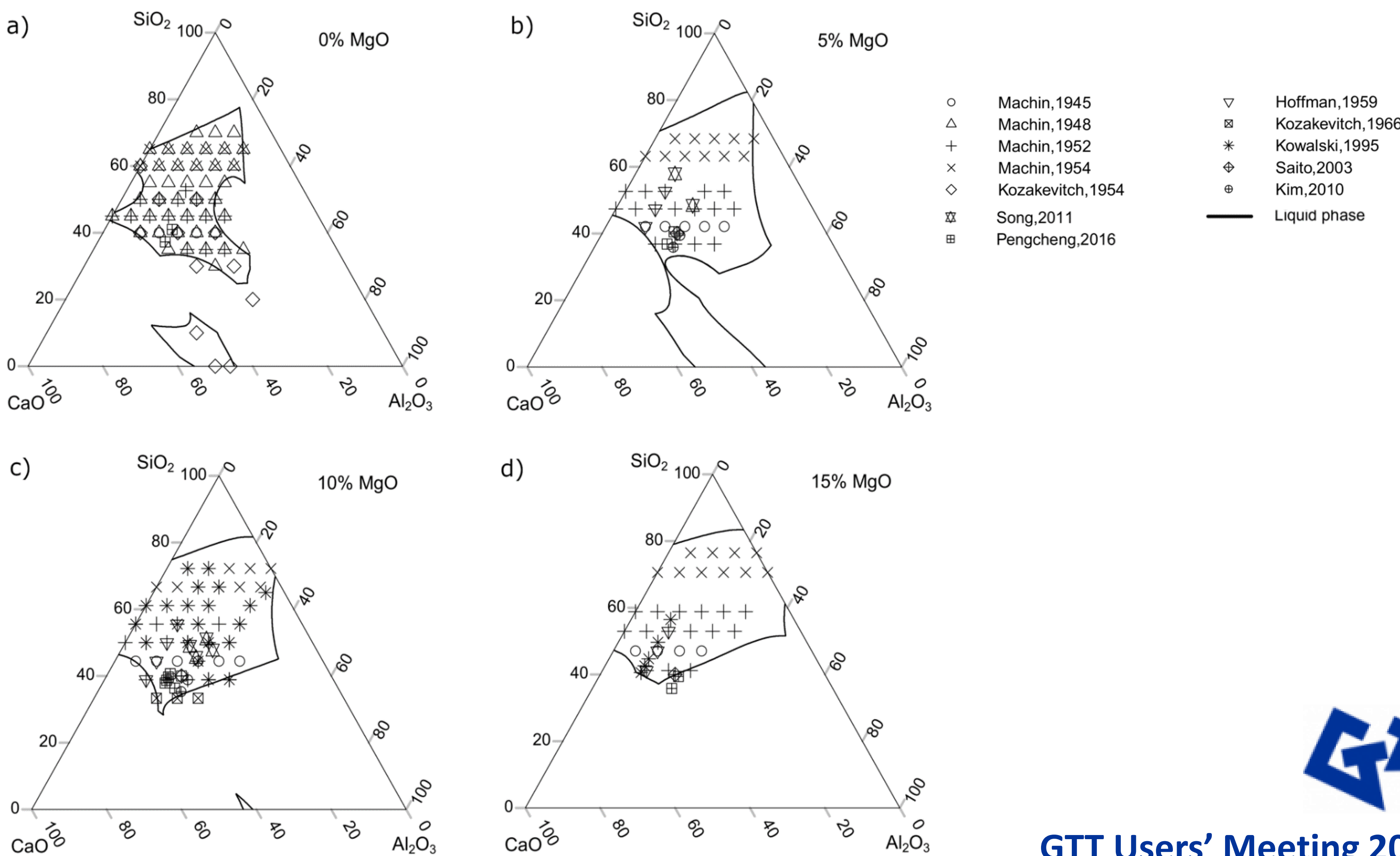
DEVELOPMENT - Experimental X calculated

- In order to verify the accuracy of the FactSage 7.2 software in the system CSAM, experimental viscosity data were collected through published works

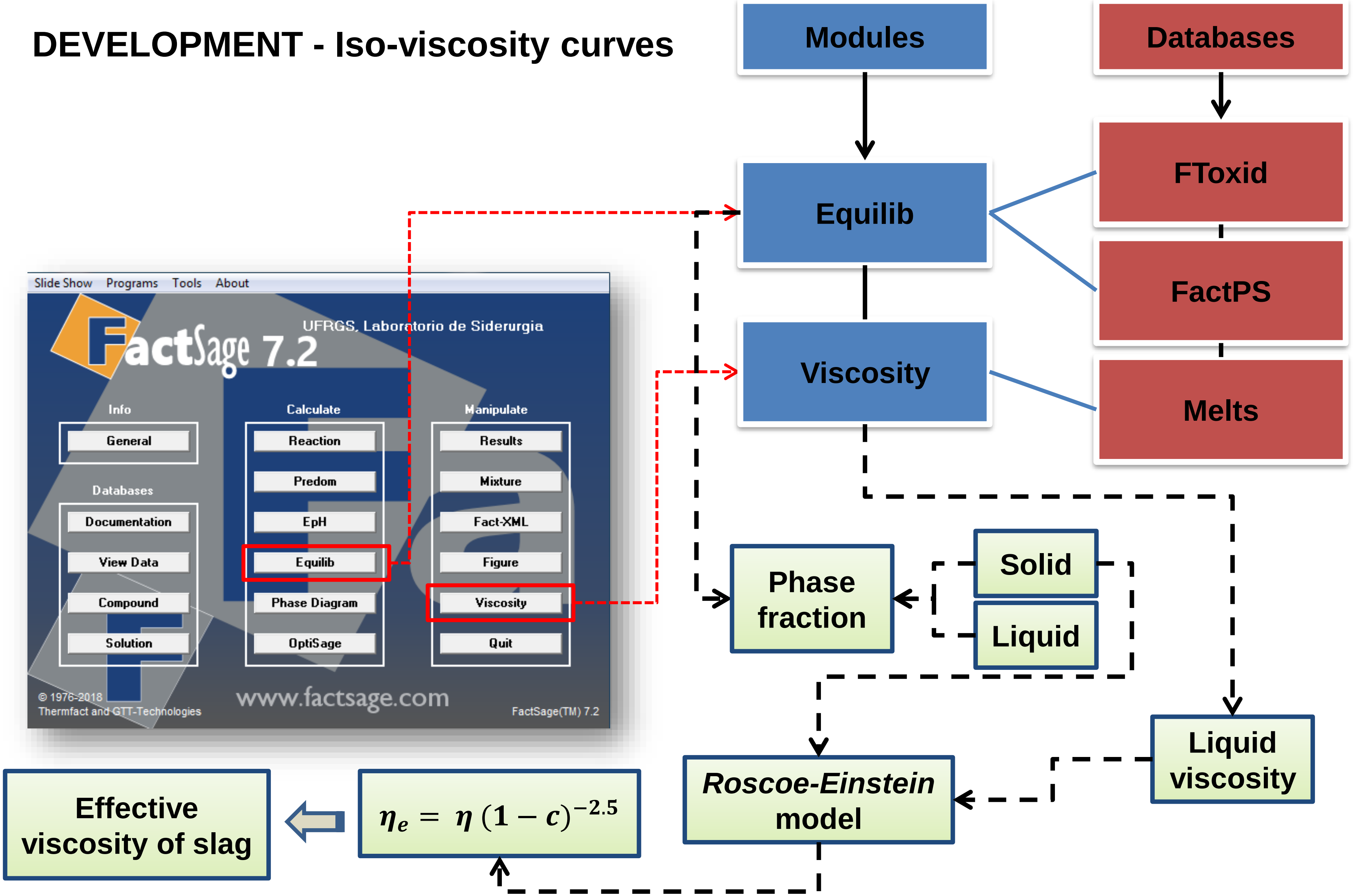
System	Author	Method	Crucible	Data
SiO_2–Al_2O_3–CaO Data: 90	Machin,1945	Oscillating	Pt	5
	Machin,1948	Oscillating	Pt	43
	Machin,1952	Oscillating	Pt	16
	Machin,1954	Oscillating	Pt	12
	Kozakevitch,1954	Rotating cylinder	Mo/W	12
	Pengcheng, 2016	Rotating cylinder	Mo	2
SiO_2–Al_2O_3–CaO–MgO Data:152	Machin,1945	Oscillating	Pt	15
	Machin,1952	Oscillating	Pt	48
	Machin,1954	Oscillating	Pt	32
	Hoffman,1959	-	-	10
	Kozakevitch,1966	Rotating cylinder	Mo/W	3
	Kowalski,1995	-	-	21
	Saito,2003	Rotating cylinder	Pt/Rh	3
	Kim,2010	Rotating cylinder	Pt/Rh	4
	Song,2011	Rotating cylinder	Mo	6
	Pengcheng, 2016	Rotating cylinder	Mo	10
Total Data				242

Collected experimental data from the literature.

DEVELOPMENT - Experimental X calculated



DEVELOPMENT - Iso-viscosity curves



DEVELOPMENT - Iso-viscosity curves

- Composition ranges of calculated slags in the viscosity database (mass%).

System	Phase	MgO	SiO_2	Al_2O_3	CaO	Calculated Data
SiO_2–Al_2O_3–CaO–MgO Data: **5976**	Liquid	0	0 - 76	0 - 54	6 - 60	*535*
	Mixture	0	0 - 43	0 - 77	23 - 100	*902*
	Liquid	5	0 - 78	0 - 60	0 - 54	*814*
	Mixture	5	0 - 42	0 - 65	29 - 95	*666*
	Liquid	10	0 - 80	0 - 58	0 - 52	*632*
	Mixture	10	0 - 46	0 - 67	12 - 90	*1025*
	Liquid	15	32 - 70	0 - 36	0 - 44	*608*
	Mixture	15	0 - 40	0 - 56	28 - 85	*794*

DEVELOPMENT - Iso-viscosity curves

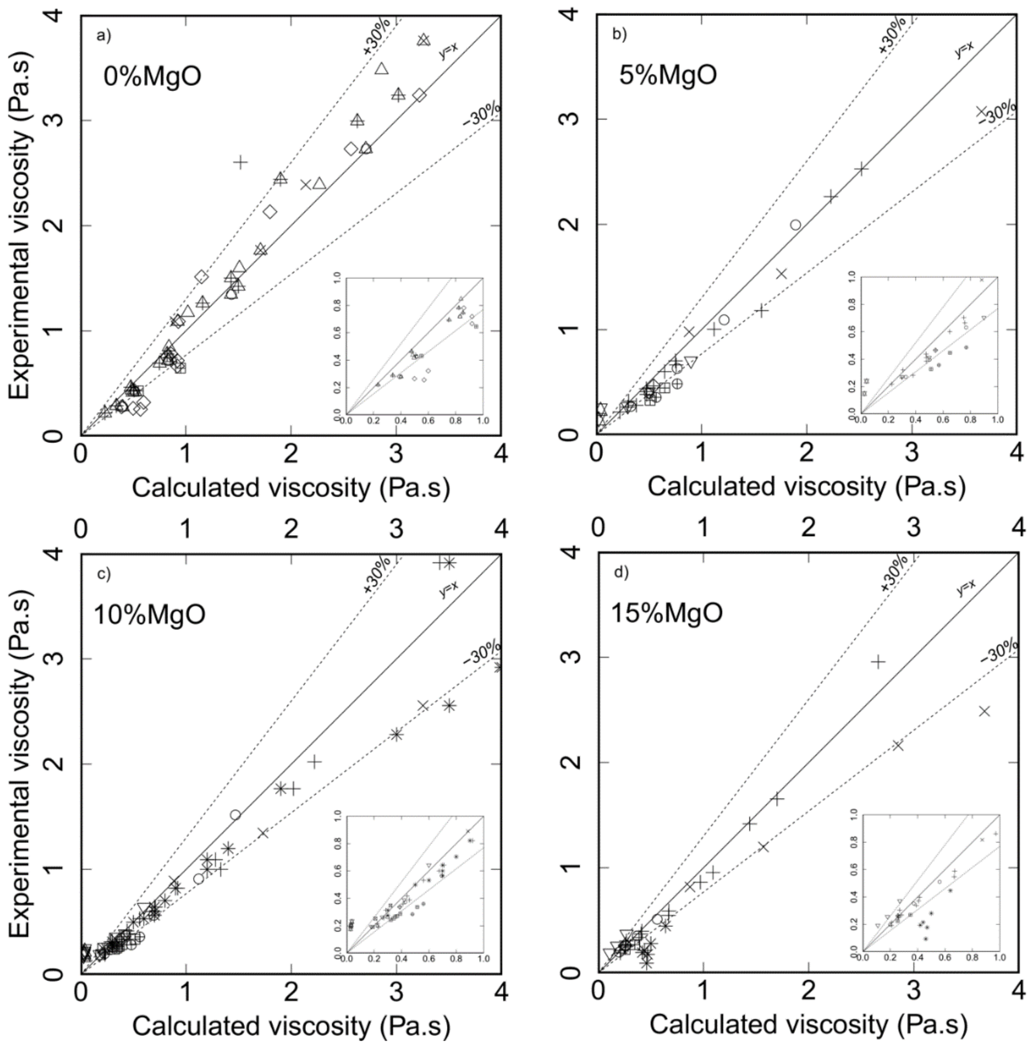
- In order to verify the convergence between the ***FactSage*** calculations and the reference viscosity data, for each slag composition, it was evaluated by the difference between measured and calculated viscosity value:

$$\delta_i = \frac{\eta_{Reference} - \eta_{FactSage}}{\eta_{Reference}}$$

- A performance analysis of the reference source on viscosity (*η*) calculations through *FactSage* was evaluated by average relative error, *Δ*, for *N* measurements of viscosity.

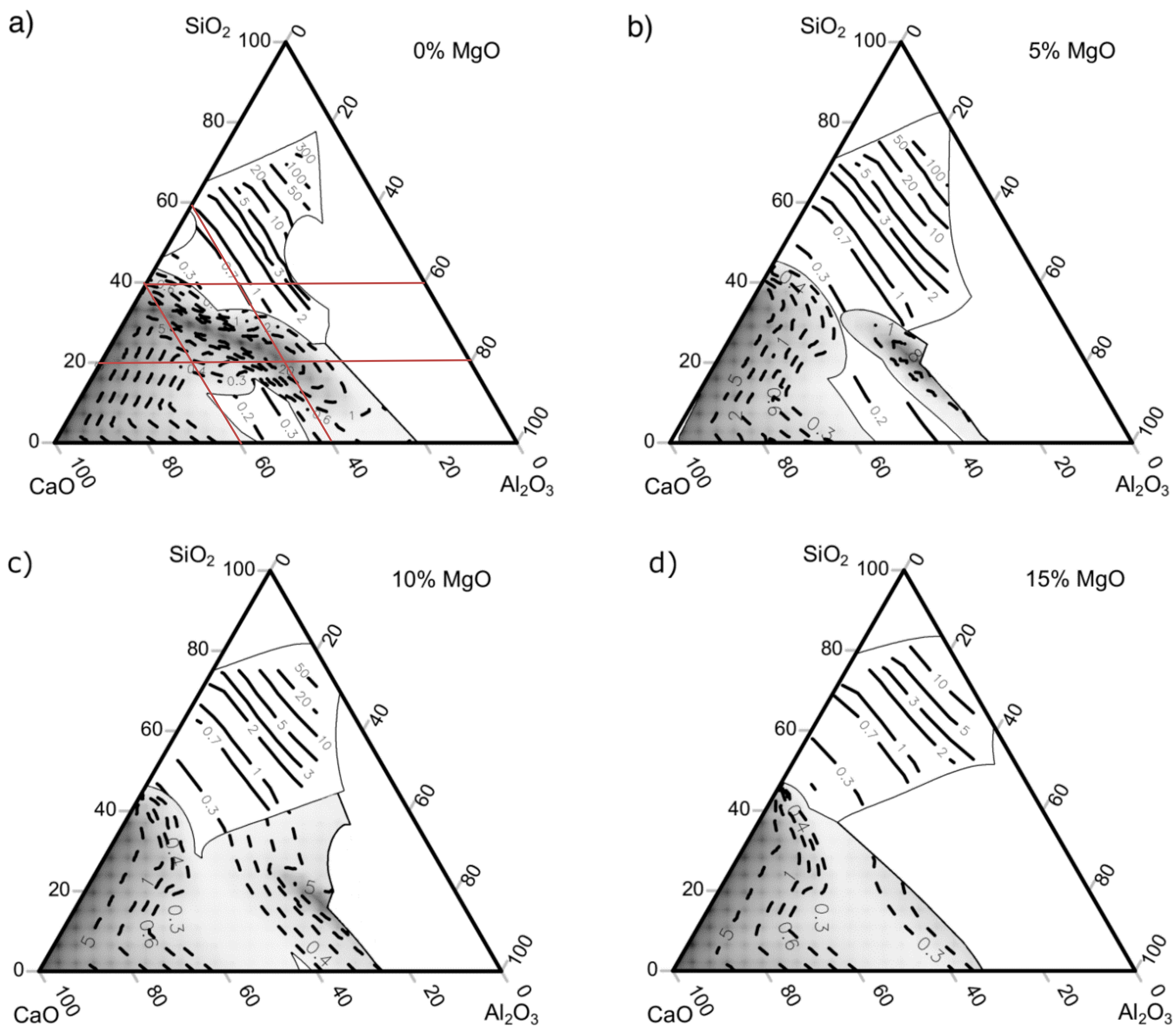
$$\varDelta = \frac{1}{N}\sum_{i=1}^{N} \delta_i \times 100\%$$

RESULTS AND DISCUSSION - Convergence data



According with Literature, the viscosity measurements values may differ from recommended values by an average of ± 30%.

RESULTS AND DISCUSSION - Iso-viscosity curves



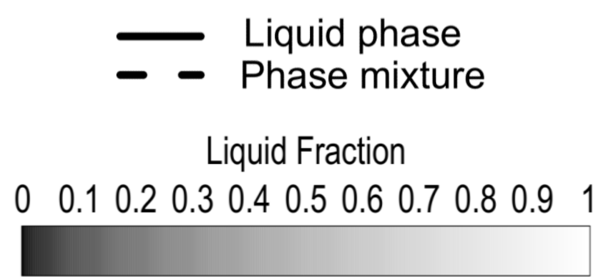
- MgO typically as a network "modifier"

- CaO

Liquid Phase: viscosity decrease

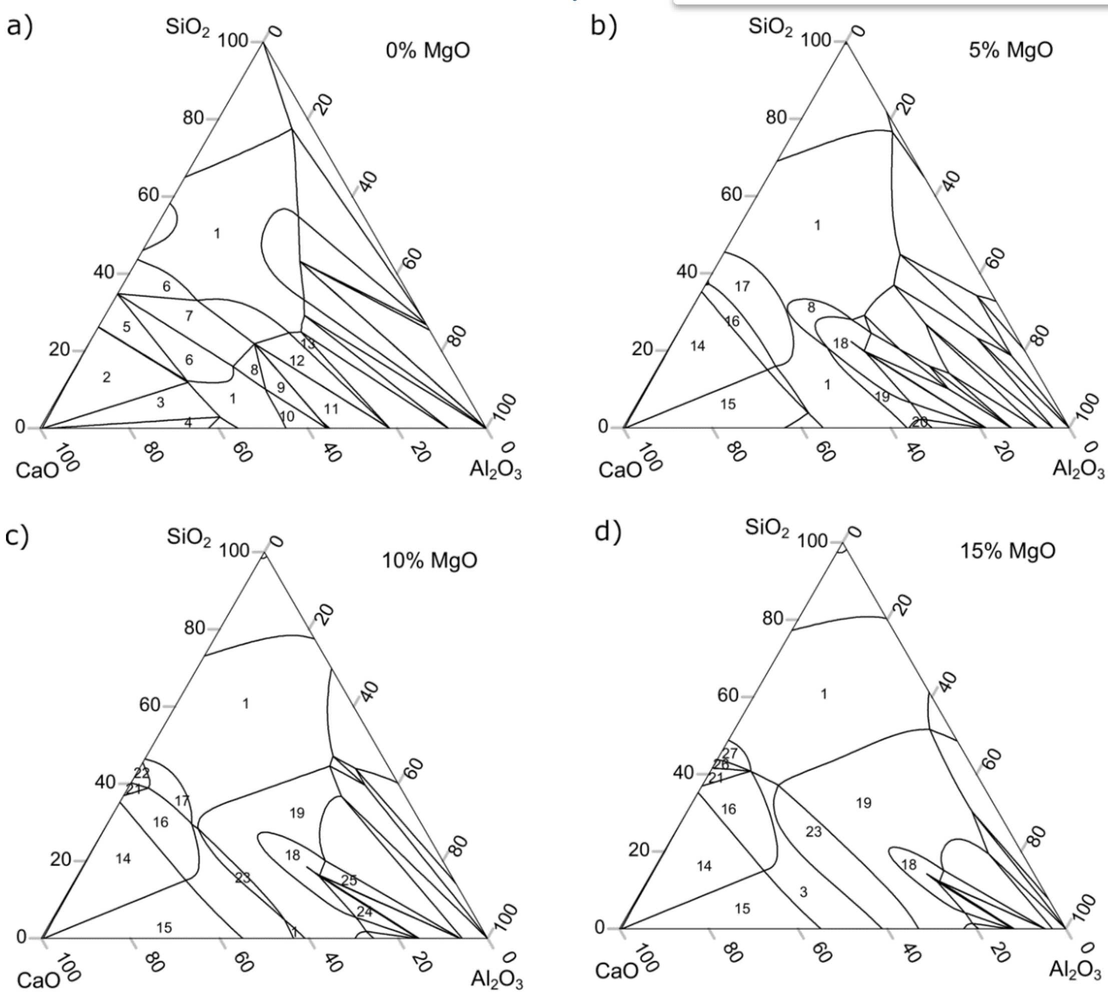
Phase Mixture: "double effect"

- Melilite



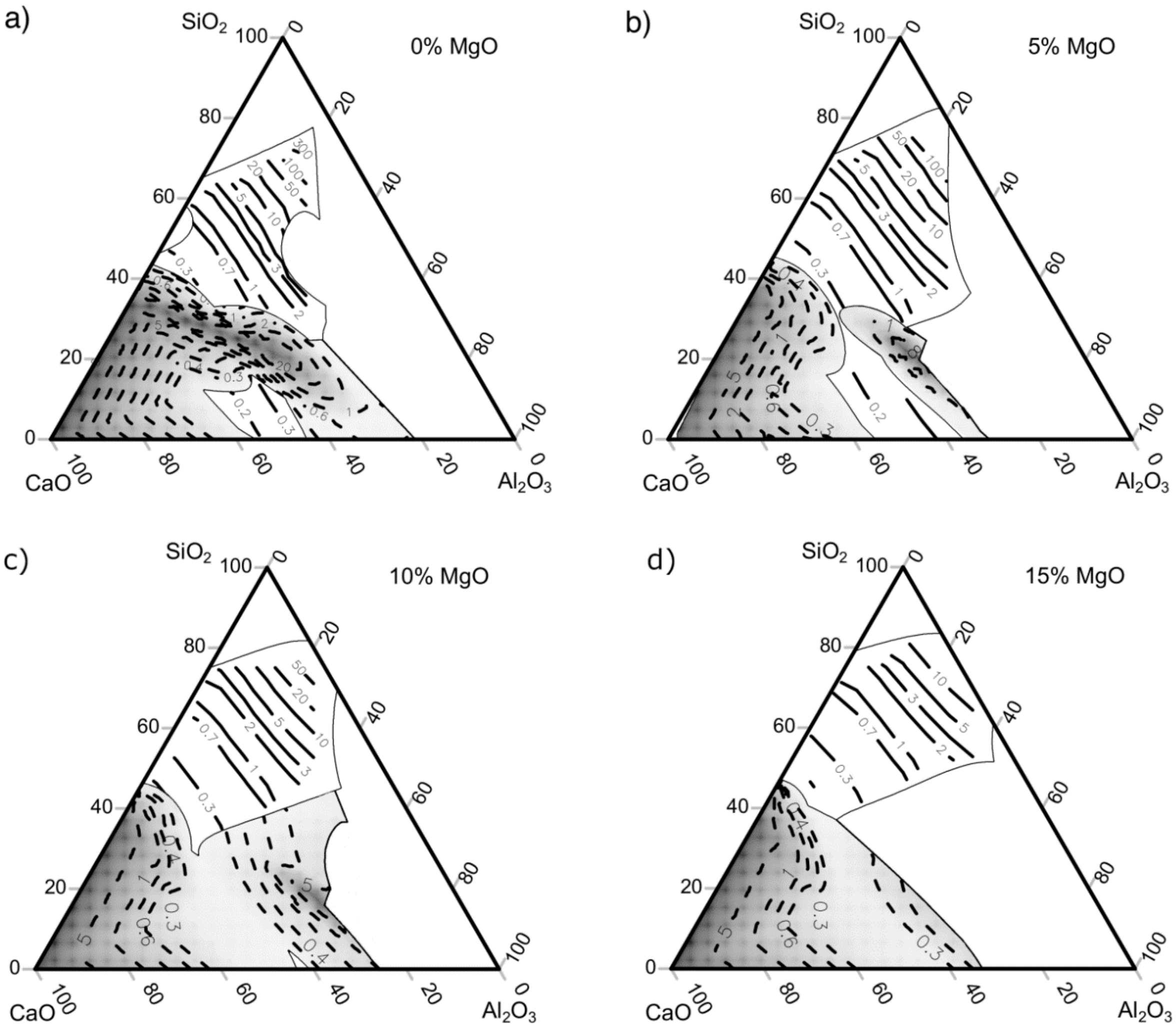
RESULTS AND DISCUSSION - Iso-viscosity curves

Melilite ($(Ca_2(Al,Mg,Fe^{2+})(Si,Al)_2O_7)$)

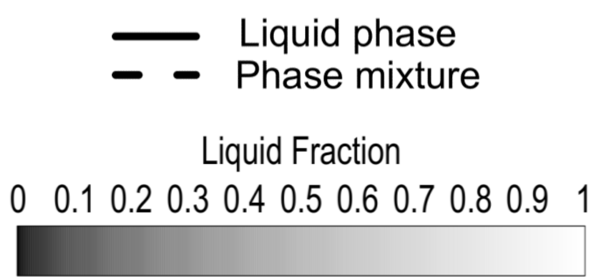


1 Slag−liq
2 Ca{3}SiO{5} + Monoxide + Slag−liq
3 Monoxide + Slag−liq
4 Ca{3}Al{2}O{6} + Monoxide + Slag−liq
5 Ca{2}SiO{4}(s3) + Ca{3}SiO{5} + Slag−liq
6 Ca{2}SiO{4}(s3) + Slag−liq
7 Ca{2}SiO{4}(s3) + Melilite + Slag−liq
8 Melilite + Slag−liq
9 CaAl{2}O{4} + Melilite + Slag−liq
10 CaAl{2}O{4} + Slag−liq
11 CaAl{2}O{4} + CaAl{4}O{7} + Melilite
12 CaAl{4}O{7} + Melilite + Slag−liq
13 CaAl{4}O{7} + Slag−liq
14 Monoxide + Monoxide#2 + Slag−liq + a−(Ca,Sr)2SiO4
15 Monoxide + Monoxide#2 + Slag−liq
16 Monoxide + Slag−liq + a−(Ca,Sr)2SiO4
17 Slag−liq + a−(Ca,Sr)2SiO4
18 Melilite + Slag−liq + Spinel
19 Slag−liq + Spinel
20 CaAl{2}O{4}+ Slag−liq + Spinel
21 Ca{3}MgSi{2}O{8} + Monoxide + Slag−liq + a−(Ca,Sr)2SiO4
22 Ca{3}MgSi{2}O{8} + Slag−liq + a−(Ca,Sr)2SiO4
23 Monoxide + Slag−liq + Spinel
24 CaAl{4}O{7} + Melilite + Slag−liq + Spinel
25 CaMg{2}Al{1}{6}O{2}{7} + Melilite + Slag−liq + Spinel
26 Ca{3}MgSi{2}O{8} + Monoxide + Slag−liq
27 Ca{3}MgSi{2}O{8} + Slag−liq

RESULTS AND DISCUSSION - Iso-viscosity curves



- Increase of SiO_2 Liquid Phase showed an expressive increase in the slag viscosity.



CONCLUSIONS

- The viscosities calculated through chemical compositions of the literature were generally within the acceptable range of relative error compared to the literature (up to 30%).
- By the analysis proposed it is possible to visualize that the effect of the MgO content decreases the viscosity in the Liquid Phase.
- The effect of the CaO oxide for the Phase Mixture showed a double effect. Initially a reduction in viscosity subsequently, tends to increase viscosity. However in Liquid Phase tends to decrease the viscosity.
- The ***FactSage 7.2*** showed to be very promising for the creation of quarteternary systems with iso-viscosity curves.

Acknowlegments

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Next steps

Influence

- Several temperatures [1500-1700ºC]
- Oxides (FeO, TiO_2, MgO)

$CaO–SiO_2–Al_2O_3$ system (%mass) at 1600°C