Phase Equilibria in the System “FeO”–CaO–SiO₂–Al₂O₃–MgO with CaO/SiO₂ 1.3

Kyoung-oh JANG,¹⁾ Xiaodong MA,¹⁾ Jinming ZHU,²⁾ Haifa XU,²⁾ Geoff WANG¹⁾ and Baojun ZHAO^{1)*}

1) School of Chemical Engineering, The University of Queensland, St Lucia, Brisbane, QLD, 4072 Australia.

2) Baoshan Iron and Steel (Baosteel) Co. Ltd, Shanghai, 201900 China.

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A series of “FeO”-containing slags are present in iron blast furnace. Phase equilibria play an important role in optimum operation of blast furnace which involves complex chemical reactions. Phase equilibria studies have been carried out in the system “FeO”–CaO–SiO₂–Al₂O₃–MgO in equilibrium with metallic iron. The technique used includes high temperature equilibration followed by quenching and electron probe X-ray microanalysis. Pseudo-ternary sections of the phase diagrams are presented in the form of (CaO+SiO₂)–Al₂O₃–MgO at fixed CaO/SiO₂ ratio of 1.3 and “FeO” concentrations of 5 and 10 wt%. This is the first systematic study in the system “FeO”–CaO–SiO₂–Al₂O₃–MgO important to the blast furnace operations. It was found that melilite, Ca₂SiO₄, merwinite, spinel and (Mg,Fe²⁺)O are the primary phase fields in the composition range investigated. Liquidus temperatures increase in the melilite and spinel primary phase fields and decrease in the merwinite and Ca₂SiO₄ primary phase fields with increasing Al₂O₃ concentration. The liquidus temperature is not sensitive with Al₂O₃ in the spinel primary phase field. Effects of MgO and “FeO” on liquidus temperature are also discussed. Extensive solid solutions can be formed in this system that have significant influence on the liquidus temperatures and the data will be used for optimisation of the thermodynamic models.

KEY WORDS: phase equilibrium; liquidus temperature; “FeO”–CaO–SiO₂–Al₂O₃–MgO system; blast furnace slag.

1. Introduction

Blast furnace (BF) has been the primary technique to produce hot metal from iron ores for many years. The principles of ironmaking with BF were summarised by Biswas¹⁾ and Geerdes *et al.*²⁾ Modern blast furnace operation confronts the new challenge of low gas permeability and formations of health accretion, resulted by increased utilization of low-grade iron ores and injection of poor-quality coal. In order to overcome these issues, it is essential to optimize slag compositions that can be described by accurate phase diagram. The slag composition is determined by the reaction of iron ores with coke/coal and fluxes. Complicated reactions in BF can form a series of slags, named by primary slag, bosh slag and final slag.^{1,2)} Only the final slag is dragged out from BF and its composition can be accurately determined. Most of investigations related to BF slags were generally focused on the final slag, which is usually described by the system CaO–SiO₂–Al₂O₃–MgO. A recent work reported by the present authors can accurately predicted phase equilibria and liquidus temperatures in the system CaO–SiO₂–Al₂O₃–MgO with CaO/SiO₂ ratio of 1.3.³⁾ However, the operating problems as introduced above cannot be well explained by

only using the properties of the final slag. The bosh and primary slags in the upper course of final slags are commonly considered to have more responsibility on the BF operations. It is very important in BF operations to identify the actual reasons causing the difficulties before any adjustments are made.

Phase diagram of the system “FeO”–SiO₂ in equilibrium with metallic iron have been summarised in Slag Atlas,⁴⁾ which mainly based on the work reported by Bowen and Schairer.⁵⁾ The eutectic points of fayalite - tridymite, fayalite - wustite and the congruent melting point of 2FeO·SiO₂ were determined to be 1 450, 1 451 and 1 478 K, respectively. It is believed that the liquid was first formed from this system in BF. The expanded system of “FeO”–CaO–SiO₂ was investigated by Bowen *et al.*^{6,7)} and Allen and Snow.⁸⁾ Effects of MgO and Al₂O₃ on the system “FeO”–SiO₂ were reported by Bowen and Schairer⁹⁾ in the system “FeO”–MgO–SiO₂ and Schairer and Yagi¹⁰⁾ in the system “FeO”–Al₂O₃–SiO₂. In multi-component systems, Muan and Osborn¹¹⁾ and Kalmanovitch and Williamson^{12,13)} reported pseudo-ternary sections of dicalcium silicate – gehlenite - “FeO” and CaO–SiO₂–Al₂O₃ with fixed “FeO” from 5 to 30 wt%. Very few experimental data are available in the system “FeO”–CaO–SiO₂–Al₂O₃–MgO in equilibrium with metallic iron which is important for BF slags. The aim of this study is to investigate phase equilibria and liquidus temperature

* Corresponding author: E-mail: baojun@uq.edu.au

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in the system “FeO”–CaO–SiO₂–Al₂O₃–MgO in equilibrium with metallic iron focusing on CaO/SiO₂ ratio of 1.3 and low-“FeO” concentrations.

2. Experimental

2.1. Selection of Pseudo-ternary System

Phase diagram for multicomponent system is usually presented in a form of pseudo-ternary section to be easily used for industrial practice. In the present study, phase diagrams in the system “FeO”–CaO–SiO₂–Al₂O₃–MgO are presented in the form of pseudo-ternary sections (CaO+SiO₂)–MgO–Al₂O₃ with CaO/SiO₂=1.3 and fixed “FeO” concentration as shown in Fig. 1. Usually, the CaO/SiO₂ ratio in final BF slag is between 1.1 and 1.3. The primary slag formed in the cohesive zone can also have CaO/SiO₂ ratio 1.3. This system is therefore related to the bosh slag and primary slag both are in equilibrium with metallic iron.

Proper selection of the pseudo-ternary sections is important for end-users of the phase diagrams. The present pseudo-ternary sections are selected for easy understanding of the experimental results. Effects of MgO and Al₂O₃ on liquidus temperatures can be evaluated independently. Liquidus temperatures can also be presented as a function of basicity (CaO+MgO)/SiO₂ or (CaO+MgO)/(SiO₂+Al₂O₃). These pseudo-ternary sections can also describe liquidus temperatures as a function of “FeO” concentration in the slags.

2.2. Experimental Procedure

The experimental procedure in the present study has been well developed at the University of Queensland,^{14–19)} which has been proven to be able to provide accurate phase equilibria data for complex slag systems. It includes high temperature equilibration, quenching and electron probe X-ray microanalysis (EPMA). CaO–SiO₂ master slag was prepared from CaCO₃ and SiO₂ to ensure the CaO/SiO₂ ratio to be 1.3 for all starting mixtures. Final mixtures were prepared by mixing high-purity powders of Fe₂O₃, Fe, MgO, Al₂O₃ and the master slag (CaO–SiO₂) in agate mortar according to the desired compositions. Excess Fe powder (20 wt% of

the mixture) was added to ensure that the slag was always equilibrated with metallic iron. About 0.3 g of the mixture was pelletized and placed in an envelope made of 0.1 mm thick Fe foil. The iron envelope was then put into an iron dish to avoid the slag spilled out by wetting flow during the equilibration. The equilibrating experiment was conducted in ultrahigh purity argon (total impurities ≤ 5 ppm, oxygen ≤ 1 ppm) gas atmosphere. Pre-melting was usually conducted for each experiment at a temperature 30 K higher than the target one for half an hour. The equilibrium process was then continued for the time from 3 to 10 hours depending on the slag composition and temperature. A Pt-30 pct Rh/Pt-6 pct Rh thermocouple was utilised inside the recrystallised alumina furnace tube near the sample. The overall absolute temperature accuracy of the experiments was estimated to be ±3 K. After the equilibration, the sample was dropped directly into iced water. The specimen was then dried on a hot plate, mounted in epoxy resin, and polished for examinations.

2.3. Sample Examination

The polished samples were coated with carbon using QT150T (Quorum Technologies) Carbon Coater for electron microscopic examination. A JXA 8200 Electron Probe Micro-analyser with Wavelength Dispersive Detectors was used for microstructural and compositional analyses. The analyses were conducted at an accelerating voltage of 15 kV and a probe current of 15 nA. The standards used for quantitative analysis were from Charles M. Taylor Co. (Stanford, California): Fe₂O₃ for Fe, Al₂O₃ for Al, MgO for Mg and CaSiO₃ for Ca and Si. The ZAF correction (atomic number: Z, adsorption: A, fluorescence: F) procedure supplied with the electron probe was applied. The average accuracy of the EPMA measurements is within 1 wt%. Both Fe²⁺ and Fe³⁺ are present in the samples, however, only the metal cation concentrations can be measured by EPMA. Since the slag was saturated with metallic iron, Fe²⁺ was dominant in the slag at low oxygen partial pressure. For the presentation purpose only, all iron cation weight measured by EPMA is calculated to “FeO” in this paper to represent iron oxide.

3. Results and Discussions

3.1. Description of the Pseudo-ternary Sections

Phase equilibria in the system “FeO”–MgO–Al₂O₃–(CaO+SiO₂) with CaO/SiO₂=1.3 is directly related to BF slags. Over 200 experiments have been carried out in this system in equilibrium with metallic iron. Typical microstructures of quenched samples are shown in Fig. 2. It can be seen from Fig. 2 that metallic iron was present in all samples to ensure the oxygen partial pressure in the condensed phases was controlled by the equilibration with iron. Figure 2(a) shows a typical microstructure quenched from melilite primary phase field. Figure 2(b) shows the equilibration of liquid with dicalcium silicate and iron. Figure 2(c) shows that liquid was in equilibrium with (Mg,Fe²⁺)O and iron. Figure 2(d) shows the equilibration of liquid with spinel and iron. The compositions of the phases obtained from EPMA are presented in Tables 1 and 2 for “FeO” concentration in liquid approximately 5 and 10 respectively. As can be seen in the tables, melilite is a complex

Fig. 1. Pseudo-ternary sections at fixed “FeO” concentrations in the system “FeO”–MgO–Al₂O₃–CaO–SiO₂ with CaO/SiO₂=1.3.

Fig. 2. Typical microstructures of the quenched slags from primary phase fields of a) melilite, b) Ca_2SiO_4 , c) $(\text{Mg}, \text{Fe}^{2+})\text{O}$ and d) Spinel.

solid solution formed by akermanite ($2\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2$), (2CaO·FeO·2SiO₂) and gehlenite ($2\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$). Other solid phases are also solid solutions represented by different formulas: spinel [$\text{Al}_2\text{O}_3 \cdot (\text{Mg}, \text{Fe}^{2+})\text{O}$], merwinite [$3\text{CaO} \cdot (\text{Mg}, \text{Fe}^{2+})\text{O} \cdot 2\text{SiO}_2$], dicalcium silicate [$2(\text{Ca}, \text{Fe}^{2+})\text{O} \cdot \text{SiO}_2$] and monoxide [$(\text{Mg}, \text{Fe}^{2+})\text{O}$]. These accurately measured solid solutions are invaluable data for optimisation of thermodynamic model.

The results are presented in the form of pseudo-ternary sections $\text{MgO}-\text{Al}_2\text{O}_3-(\text{CaO}+\text{SiO}_2)$ with $\text{CaO}/\text{SiO}_2=1.3$ and fixed “FeO” concentrations. CaO/SiO_2 ratio and “FeO” concentration in the solid phases Ca_2SiO_4 , merwinite and melilite are different from those in the liquid. Precipitation of these solid phases will result in different CaO/SiO_2 ratio and “FeO” concentration in the liquid phase from the target ones. Oxidisation of metallic iron also increased the “FeO” concentration in the liquid phase. It was therefore difficult to obtain the required CaO/SiO_2 ratio and “FeO” concentration in the liquid phase. A large number of experiments had to be carried out and the experimental data have to be analysed carefully to construct the phase diagram.

The liquid compositions listed in Tables 1 and 2 are used to construct two pseudo-ternary sections $\text{MgO}-\text{Al}_2\text{O}_3-(\text{CaO}+\text{SiO}_2)$ with $\text{CaO}/\text{SiO}_2=1.3$ and fixed “FeO” concentrations of 5 and 10 wt% respectively as shown in Figs. 3 and 4. The symbols in the figures show experimentally determined liquid compositions. Thick lines in the figures are the boundaries between primary phase fields and thin lines are isotherms derived from the experimental data. The liquidus can be accurately determined by the present technique if primary phase is present. The equilibration temperature was controlled within ± 3 K. The compositions of the liquid and solid phases present in the quenched sample were accurately measured by EPMA. However, as described above it is not straightforward to draw the isotherms from the experimental data. For example, the liquid phase in the isotherms shown in Fig. 3 must have $\text{CaO}/\text{SiO}_2=1.3$ and fixed “FeO” concentrations of 5 wt%. The experimentally determined points do not always have the exact CaO/SiO_2 ratio of 1.3 and “FeO” concentrations of 5 wt%. Effects of

Table 1. Experimental results of the system “FeO”–CaO–SiO₂–MgO–Al₂O₃ with $\text{CaO}/\text{SiO}_2=1.3$ and 5 wt% “FeO”.

Experiment No.	Temperature (K)	Phases	Composition (wt%)					CaO/SiO ₂
			CaO	SiO ₂	MgO	Al ₂ O ₃	“FeO”	
Liquid only								
382	1 673	Liquid	37.8	29.6	11.7	16.2	4.7	1.28
Liquid with one solid phase								
Melilite primary phase field								
127	1 673	Liquid	42.1	32.3	5.5	12.4	7.6	1.30
		Melilite	41.6	27.3	3.5	26.7	0.9	
180	1 673	Liquid	40.0	31.0	7.4	14.2	7.4	1.29
		Melilite	41.2	26.3	3.0	28.9	0.5	
256	1 673	Liquid	39.0	32.6	7.5	13.8	7.0	1.20
		Melilite	39.1	28.1	3.3	28.9	0.6	
219	1 703	Liquid	38.4	34.8	2.5	16.9	7.4	1.10
		Melilite	38.7	25.1	1.2	34.2	0.7	
220	1 703	Liquid	42.8	32.0	5.0	14.4	5.8	1.34
		Melilite	42.0	26.1	2.9	28.4	0.6	
221	1 703	Liquid	38.1	30.7	8.5	16.0	6.6	1.24
		Melilite	40.7	27.0	3.0	28.9	0.5	
241	1 703	Liquid	42.5	31.3	4.8	14.7	6.7	1.36
		Melilite	42.0	25.9	2.8	28.9	0.4	
303	1 703	Liquid	40.0	29.3	7.7	16.9	5.7	1.37
		Melilite	41.8	25.3	2.6	30.1	0.3	
318	1 703	Liquid	44.4	33.3	0.1	14.9	7.4	1.33
		Melilite	42.0	22.2	0.1	35.0	0.7	
319	1 703	Liquid	39.8	29.3	7.9	17.7	5.3	1.36
		Melilite	41.9	25.1	2.5	30.3	0.2	
320	1 703	Liquid	43.5	32.1	4.8	14.4	5.1	1.36
		Melilite	42.0	25.4	2.7	29.7	0.3	
326	1 703	Liquid	42.9	34.5	0.0	15.9	6.7	1.24
		Melilite	40.9	22.6	0.0	35.7	0.7	
328	1 703	Liquid	41.5	30.7	5.1	15.9	6.8	1.35
		Melilite	42.3	25.0	2.5	29.7	0.5	
272	1 723	Liquid	43.1	35.3	0.0	17.0	4.6	1.22
		Melilite	38.8	23.2	0.0	37.7	0.3	
274	1 723	Liquid	40.6	34.2	0.0	18.5	6.6	1.19
		Melilite	38.3	23.4	0.0	37.6	0.7	
314	1 723	Liquid	41.0	30.3	3.8	16.9	7.9	1.35
		Melilite	41.5	24.5	1.7	31.7	0.5	
443	1 723	Liquid	40.0	29.9	5.0	18.6	6.3	1.34
		Melilite	41.7	25.0	2.1	30.9	0.2	
446	1 723	Liquid	43.3	30.9	2.0	16.4	7.2	1.40
		Melilite	42.2	23.3	1.2	33.0	0.4	
452	1 723	Liquid	45.3	33.1	0.2	15.6	5.5	1.37
		Melilite	42.1	22.0	0.2	35.5	0.3	
454	1 723	Liquid	39.7	30.6	5.5	18.3	5.8	1.30
		Melilite	40.7	25.3	2.2	31.4	0.4	
Spinel primary phase field								
511	1 703	Liquid	37.3	28.9	9.6	19.2	5.0	1.29
		spinel	0.2	0.0	27.1	70.3	2.4	
512	1 703	Liquid	36.6	28.6	12.4	16.7	5.8	1.28
		spinel	0.2	0.0	27.5	70.8	1.5	
5	1 723	Liquid	36.6	28.4	9.7	19.4	5.6	1.29

		Spinel	0.2	0.0	26.6	69.7	3.1	
<i>Ca₂SiO₄ primary phase field</i>								
399	1 673	Liquid	44.4	33.4	2.9	11.4	7.7	1.33
		Ca ₂ SiO ₄	62.5	33.3	1.2	0.3	2.6	
403	1 703	Liquid	42.5	33.5	7.8	10.3	5.6	1.27
		Ca ₂ SiO ₄	59.8	34.4	3.3	0.2	2.1	
473	1 703	Liquid	43.6	35.4	2.8	10.8	7.4	1.23
		Ca ₂ SiO ₄	61.3	34.7	1.1	0.3	2.5	
411	1 723	Liquid	42.1	34.2	8.6	8.6	6.6	1.23
		Ca ₂ SiO ₄	59.6	35.3	3.3	0.2	1.5	
465	1 723	Liquid	44.7	38.3	0.3	9.3	7.4	1.17
		Ca ₂ SiO ₄	62.1	34.8	0.1	0.3	2.6	
469	1 723	Liquid	42.0	35.5	5.3	9.3	7.9	1.18
		Ca ₂ SiO ₄	60.7	34.9	2.1	0.2	2.1	
<i>Merwinite primary phase field</i>								
298	1 673	Liquid	40.6	31.0	8.2	13.0	6.8	1.31
		Merwinite	51.2	35.9	11.8	0.1	0.9	
299	1 673	Liquid	39.4	30.0	9.3	13.9	7.2	1.31
		Merwinite	51.2	35.8	11.9	0.1	0.9	
Liquid with more solid phases								
21	1 673	Liquid	46.0	36.2	0.0	12.5	5.2	1.27
		Melilite	40.1	22.7	0.0	36.4	0.5	
		Ca ₂ SiO ₄	62.9	35.0	0.0	0.4	1.7	
72	1 673	Liquid	45.3	36.4	2.9	11.6	3.6	1.24
		Melilite	41.3	26.2	2.8	29.3	0.3	
		Ca ₂ SiO ₄	61.4	34.9	1.4	0.5	1.7	
316	1 673	Liquid	41.5	31.4	8.0	13.2	5.8	1.32
		Melilite	41.9	27.5	4.3	24.8	1.5	
		Merwinite	51.5	35.9	11.6	0.1	0.9	
381	1 673	Liquid	37.9	29.2	11.7	16.3	4.9	1.30
		Spinel	0.3	0.1	27.9	70.2	1.5	
		Merwinite	50.7	36.4	12.4	0.1	0.4	
457	1 673	Liquid	40.9	31.4	7.2	13.1	7.3	1.30
		Ca ₂ SiO ₄	59.6	35.2	2.9	0.2	2.0	
		Merwinite	51.0	36.4	11.7	0.1	0.8	
433	1 703	Liquid	38.9	29.3	12.3	13.5	6.0	1.33
		Merwinite	51.4	35.7	12.3	0.1	0.5	
		(Mg,Fe ²⁺)O	0.3	0.0	84.6	0.8	14.4	
505	1 703	Liquid	35.6	28.1	7.8	20.5	7.9	1.27
		Melilite	41.1	24.5	1.8	32.1	0.5	
		spinel	0.3	0.0	26.1	70.0	3.6	
311	1 723	Liquid	36.6	27.1	7.6	23.0	5.7	1.35
		Melilite	41.4	24.1	1.6	32.7	0.2	
		Spinel	0.1	0.0	26.6	71.1	2.3	
458	1 673	Liquid	42.4	33.0	6.7	13.0	4.9	1.28
		Melilite	40.9	26.7	3.1	28.9	0.4	
		Ca ₂ SiO ₄	60.4	34.9	2.7	0.3	1.7	
		Merwinite	51.3	36.0	11.6	0.1	0.9	
315	1 673	Liquid	42.8	32.2	7.2	12.8	5.0	1.33
		Melilite	41.7	26.9	3.3	27.7	0.3	
		Ca ₂ SiO ₄	62.1	33.9	2.6	0.2	1.3	
		Merwinite	51.7	36.0	11.6	0.1	0.6	

Table 2. Data resulted from the system “FeO”–CaO–SiO₂–MgO–Al₂O₃ with CaO/SiO₂=1.3 and 10 wt% “FeO”.

Experiment No.	Temperature (K)	Phases	Composition (wt%)					CaO/
			CaO	SiO ₂	MgO	Al ₂ O ₃	“FeO”	SiO ₂
Liquid only								
128	1 673	Liquid	39.2	29.4	5.4	12.9	12.9	1.33
179	1 673	Liquid	37.3	29.0	6.9	13.6	12.9	1.28
188	1 673	Liquid	39.9	30.2	5.1	11.9	12.9	1.32
201	1 673	Liquid	42.2	31.7	4.6	11.6	10.0	1.33
323	1 673	Liquid	39.1	30.8	7.7	14.6	7.8	1.27
324	1 673	Liquid	40.5	31.8	4.6	12.9	10.3	1.27
393	1 673	Liquid	44.1	35.3	0.1	11.5	9.0	1.25
211	1 703	Liquid	42.4	32.5	0.0	15.0	10.0	1.30
301	1 703	Liquid	41.8	31.5	0.1	14.0	12.4	1.33
302	1 703	Liquid	42.3	31.7	0.0	14.6	11.1	1.33
329	1 703	Liquid	39.3	30.5	2.7	14.6	12.9	1.28
422	1 703	Liquid	34.3	26.0	9.0	18.0	12.7	1.32
424	1 703	Liquid	34.7	26.4	11.4	16.3	11.3	1.31
437	1 703	Liquid	34.8	26.8	12.3	14.8	11.4	1.30
503	1 703	Liquid	39.2	30.4	8.6	10.7	10.9	1.29
504	1 703	Liquid	34.6	26.7	11.6	15.0	11.7	1.30
41	1 723	Liquid	36.0	27.5	10.2	13.0	12.7	1.31
66	1 723	Liquid	36.6	27.8	9.5	16.5	9.2	1.32
113	1 723	Liquid	35.3	26.5	5.4	22.1	10.7	1.33
250	1 723	Liquid	36.0	28.4	3.0	20.8	11.8	1.27
287	1 723	Liquid	36.9	28.2	4.2	17.8	12.9	1.31
389	1 723	Liquid	35.4	27.4	10.9	17.3	9.0	1.29
427	1 723	Liquid	34.4	26.5	13.4	16.5	9.2	1.30
444	1 723	Liquid	36.2	26.4	6.5	21.0	9.6	1.37
447	1 723	Liquid	34.6	26.7	11.7	16.8	9.9	1.29
497	1 723	Liquid	33.9	26.5	12.3	14.7	12.3	1.28
498	1 723	Liquid	35.5	27.7	11.9	12.7	11.9	1.28
Liquid with one solid phase								
Melilite primary phase field								
515	1 653	Liquid	43.6	34.5	0.1	12.1	9.7	1.27
		Melilite	41.0	22.8	0.1	34.8	1.4	
516	1 653	Liquid	39.8	31.0	6.8	13.1	9.3	1.28
		Melilite	41.0	25.9	2.6	29.8	0.8	
518	1 653	Liquid	39.8	30.0	4.6	13.2	12.4	1.33
		Melilite	41.2	25.4	2.1	30.3	1.1	
27	1 673	Liquid	40.1	32.0	2.9	13.2	11.7	1.25
		Melilite	40.2	26.0	2.1	30.5	1.2	
28	1 673	Liquid	39.7	32.0	3.2	13.4	11.7	1.24
		Melilite	40.3	25.8	2.0	30.4	1.4	
29	1 673	Liquid	37.9	31.3	3.4	14.4	13.0	1.21
		Melilite	40.3	25.5	1.8	31.2	1.2	
33	1 673	Liquid	38.4	30.6	6.1	14.5	10.4	1.25
		Melilite	40.2	26.3	2.6	29.9	0.9	

70	1 673	Liquid	42.4	33.3	0.1	13.1	10.8	1.28
		Melilite	40.9	23.0	0.0	34.5	1.5	
73	1 673	Liquid	39.8	31.3	3.2	13.6	11.7	1.27
		Melilite	40.9	25.4	1.9	30.7	1.1	
127	1 673	Liquid	42.1	32.3	5.5	12.4	7.6	1.30
		Melilite	41.6	27.3	3.5	26.7	0.9	
130	1 673	Liquid	38.5	30.2	5.7	14.3	11.0	1.27
		Melilite	41.0	27.2	3.3	27.0	1.5	
165	1 673	Liquid	39.1	30.1	4.0	14.9	11.7	1.30
		Melilite	39.8	25.8	2.3	30.8	1.2	
166	1 673	Liquid	39.0	30.0	4.3	15.4	10.8	1.30
		Melilite	39.3	24.8	1.9	32.9	1.1	
174	1 673	Liquid	41.1	32.6	1.9	13.2	11.0	1.26
		Melilite	40.9	24.8	1.5	31.6	1.2	
180	1 673	Liquid	40.0	31.0	7.4	14.2	7.4	1.29
		Melilite	41.2	26.3	3.0	28.9	0.5	
197	1 673	Liquid	41.8	33.1	4.5	12.2	8.4	1.26
		Melilite	41.0	26.5	2.8	28.8	0.8	
253	1 673	Liquid	39.5	30.9	4.7	14.3	10.6	1.28
		Melilite	40.8	26.4	2.4	30.0	0.4	
255	1 673	Liquid	38.1	29.3	5.0	15.4	12.3	1.30
		Melilite	41.1	25.7	2.0	30.8	0.3	
256	1 673	Liquid	39.0	32.6	7.5	13.8	7.0	1.20
		Melilite	39.1	28.1	3.3	28.9	0.6	
261	1 673	Liquid	36.3	30.5	7.5	15.6	10.1	1.19
		Melilite	38.9	26.7	2.4	31.1	0.7	
262	1 673	Liquid	35.9	27.9	6.3	16.6	13.2	1.29
		Melilite	41.5	25.3	2.2	30.4	0.6	
322	1 673	Liquid	43.0	34.0	0.1	13.5	9.5	1.27
		Melilite	41.2	22.8	0.1	34.6	1.4	
325	1 673	Liquid	41.7	32.8	3.0	13.2	9.4	1.27
		Melilite	40.8	26.1	2.2	29.8	1.1	
335	1 673	Liquid	40.5	32.7	0.0	15.1	11.6	1.24
		Melilite	41.1	23.0	0.0	34.1	1.8	
336	1 673	Liquid	37.4	29.5	5.3	16.9	10.9	1.27
		Melilite	41.3	25.3	2.1	30.5	0.8	
337	1 673	Liquid	39.5	32.1	2.3	14.7	11.5	1.23
		Melilite	41.3	23.9	1.2	32.5	1.1	
213	1 703	Liquid	35.6	32.2	4.9	18.4	9.0	1.11
		Melilite	38.8	25.8	1.9	32.8	0.7	
214	1 703	Liquid	43.2	33.4	0.0	15.0	8.3	1.29
		Melilite	41.6	22.4	0.0	35.2	0.8	
219	1 703	Liquid	38.4	34.8	2.5	16.9	7.4	1.10
		Melilite	38.7	25.1	1.2	34.2	0.7	
233	1 703	Liquid	40.0	30.2	4.4	14.9	10.5	1.32
		Melilite	41.2	24.6	1.6	31.7	0.9	
234	1 703	Liquid	39.4	31.4	3.1	16.6	9.4	1.26
		Melilite	40.6	24.5	1.4	32.6	0.8	

318	1 703	Liquid	44.4	33.3	0.1	14.9	7.4	1.34
		Melilite	42.0	22.2	0.1	35.0	0.7	
340	1 703	Liquid	35.9	28.8	4.1	19.8	11.4	1.25
		Melilite	40.7	24.1	1.2	33.2	0.7	
89	1 723	Liquid	39.2	25.8	4.7	20.6	9.8	1.52
		Melilite	41.2	23.3	1.1	34.0	0.4	
235	1 723	Liquid	40.4	32.8	0.0	18.6	8.2	1.23
		Melilite	40.7	22.6	0.0	35.9	0.8	
265	1 723	Liquid	34.9	28.0	2.7	22.1	12.2	1.25
		Melilite	40.9	23.7	1.0	33.7	0.7	
270	1 723	Liquid	40.5	32.3	0.0	18.8	8.3	1.26
		Melilite	41.1	22.5	0.0	35.5	0.8	
314	1 723	Liquid	41.0	30.3	3.8	16.9	7.9	1.35
		Melilite	41.5	24.5	1.7	31.7	0.5	
332	1 723	Liquid	38.2	31.2	2.1	18.7	9.8	1.22
		Melilite	40.7	23.8	1.0	33.8	0.7	
333	1 723	Liquid	37.0	29.1	3.5	21.4	9.0	1.27
		Melilite	41.1	23.8	1.1	33.5	0.6	
343	1 723	Liquid	32.5	25.1	4.8	26.8	10.8	1.29
		Melilite	40.9	23.5	1.0	34.0	0.5	
451	1 723	Liquid	35.3	25.8	6.4	24.0	8.4	1.37
		Melilite	41.9	23.6	1.5	32.6	0.4	
Spinel primary phase field								
47	1 673	Liquid	35.8	26.0	10.7	15.3	11.9	1.38
		Spinel	0.2	0.0	26.6	69.1	3.6	
507	1 703	Liquid	34.7	27.3	9.5	18.3	10.1	1.27
		spinel	0.1	0.0	27.1	70.5	2.3	
291	1 723	Liquid	32.6	24.4	4.8	26.3	11.9	1.33
		spinel	0.1	0.0	22.4	68.7	8.7	
292	1 723	Liquid	32.7	24.2	4.7	26.8	11.6	1.35
		spinel	0.1	0.0	22.5	68.7	8.7	
Ca2SiO4 primary phase field								
520	1 653	Liquid	41.6	31.3	5.6	11.5	9.9	1.33
		Ca2SiO4	60.5	34.6	2.2	0.2	2.5	
532	1 653	Liquid	43.0	33.9	4.2	11.0	7.8	1.27
		Ca2SiO4	61.0	34.8	1.7	0.3	2.2	
399	1 673	Liquid	44.4	33.4	2.9	11.4	7.7	1.33
		Ca2SiO4	62.5	33.3	1.2	0.3	2.6	
400	1 673	Liquid	43.2	32.6	2.5	10.7	10.7	1.33
		Ca2SiO4	61.3	33.5	1.1	0.3	3.7	
459	1 673	Liquid	44.9	34.7	0.1	10.8	9.4	1.29
		Ca2SiO4	60.8	34.6	0.1	0.4	3.9	
405	1 703	Liquid	42.5	33.2	4.4	10.0	9.7	1.28
		Ca2SiO4	60.4	34.2	1.8	0.2	3.3	
408	1 703	Liquid	42.8	33.7	2.4	9.2	12.0	1.27
		Ca2SiO4	60.4	35.0	0.9	0.2	3.4	
461	1 703	Liquid	43.5	35.3	0.2	10.6	10.4	1.23
		Ca2SiO4	61.8	34.1	0.1	0.3	3.6	

463	1 703	Liquid	42.2	33.6	0.2	8.8	15.2	1.25
		Ca ₂ SiO ₄	61.2	34.5	0.1	0.2	3.8	
473	1 703	Liquid	43.6	35.4	2.8	10.8	7.4	1.23
		Ca ₂ SiO ₄	61.3	34.7	1.1	0.3	2.5	
474	1 703	Liquid	40.6	33.1	6.6	10.5	9.3	1.23
		Ca ₂ SiO ₄	59.2	35.4	2.8	0.2	2.4	
412	1 723	Liquid	40.5	32.5	7.9	7.4	11.7	1.25
		Ca ₂ SiO ₄	59.2	35.3	3.0	0.1	2.4	
413	1 723	Liquid	41.8	32.6	4.4	7.8	13.4	1.28
		Ca ₂ SiO ₄	60.2	34.8	1.7	0.2	3.1	
465	1 723	Liquid	44.7	38.3	0.3	9.3	7.4	1.17
		Ca ₂ SiO ₄	62.1	34.8	0.1	0.3	2.6	
469	1 723	Liquid	42.0	35.5	5.3	9.3	7.9	1.18
		Ca ₂ SiO ₄	60.7	34.9	2.1	0.2	2.1	
470	1 723	Liquid	39.6	29.8	9.5	8.2	12.6	1.33
		Ca ₂ SiO ₄	59.3	35.0	3.4	0.1	2.1	
479	1 723	Liquid	43.9	33.9	2.4	8.6	11.0	1.30
		Ca ₂ SiO ₄	60.5	34.9	1.0	0.2	3.2	
480	1 723	Liquid	40.7	31.3	6.6	7.8	13.5	1.30
		Ca ₂ SiO ₄	59.4	34.9	2.6	0.2	2.9	
<i>Merwinite primary phase field</i>								
523	1 653	Liquid	40.8	30.5	6.4	11.9	10.4	1.34
		Merwinite	51.3	35.9	11.1	0.1	1.6	
524	1 653	Liquid	39.5	28.9	7.5	12.2	12.0	1.37
		Merwinite	50.9	36.1	11.1	0.1	1.7	
15	1 673	Liquid	37.7	28.8	9.1	13.5	10.6	1.31
		Merwinite	50.2	36.6	11.8	0.1	1.2	
36	1 673	Liquid	37.6	28.4	8.8	12.5	12.7	1.32
		Merwinite	50.4	36.4	11.7	0.1	1.5	
296	1 673	Liquid	40.5	30.8	7.0	11.1	10.3	1.32
		Merwinite	51.1	35.8	11.5	0.1	1.4	
297	1 673	Liquid	40.1	30.1	8.2	12.1	9.3	1.33
		Merwinite	51.1	35.8	11.8	0.1	1.1	
299	1 673	Liquid	39.4	30.0	9.3	13.9	7.2	1.31
		Merwinite	51.2	35.8	11.9	0.1	0.9	
317	1 673	Liquid	39.8	29.3	9.3	12.9	8.6	1.36
		Merwinite	51.8	35.3	11.7	0.1	1.0	
508	1 703	Liquid	39.4	30.6	9.9	11.3	8.7	1.29
		Merwinite	51.1	36.2	11.7	0.1	0.9	
514	1 703	Liquid	38.7	29.9	9.8	10.3	11.3	1.29
		Merwinite	51.0	36.1	11.7	0.2	1.0	
466	1 723	Liquid	38.8	30.9	9.4	9.1	11.8	1.26
		Merwinite	51.2	36.0	12.1	0.1	0.6	
<i>(Mg,Fe²⁺)O primary phase field</i>								
434	1 703	Liquid	37.3	27.9	10.7	11.7	12.4	1.34
		(Mg,Fe ²⁺)O	0.2	0.0	70.8	0.7	28.2	
438	1 703	Liquid	34.5	26.1	11.9	14.3	13.2	1.32
		(Mg,Fe ²⁺)O	0.3	0.0	70.1	0.9	28.7	

493	1 723	Liquid	36.0	27.2	12.8	14.7	9.2	1.32
		(Mg,Fe ²⁺)O	0.2	0.0	80.8	0.9	17.9	
Liquid with more solid phases								
519	1 653	Liquid	44.3	34.2	0.1	11.7	9.7	1.30
		Melilite	41.0	23.0	0.1	34.2	1.6	
		Ca ₂ SiO ₄	61.9	34.6	0.0	0.3	3.1	
521	1 653	Liquid	42.8	33.1	1.7	11.3	11.0	1.29
		Melilite	40.9	25.1	1.5	31.0	1.4	
		Ca ₂ SiO ₄	61.6	34.5	0.7	0.2	2.9	
522	1 653	Liquid	41.6	31.6	3.6	11.7	11.5	1.31
		Melilite	41.0	25.2	1.8	30.9	1.1	
		Ca ₂ SiO ₄	60.9	34.8	1.4	0.2	2.6	
334	1 673	Liquid	35.3	28.8	7.9	18.0	10.0	1.23
		Melilite	41.3	25.5	2.4	30.4	0.5	
		Spinel	0.2	0.0	24.5	68.8	6.4	
79	1 673	Liquid	37.4	28.2	8.8	14.9	10.4	1.33
		Melilite	41.2	27.7	3.7	27.0	0.2	
		Merwinite	51.0	36.0	11.5	0.1	1.2	
295	1 673	Liquid	40.0	30.5	7.1	10.2	12.0	1.31
		Ca ₂ SiO ₄	59.9	34.8	2.6	0.2	2.3	
		Merwinite	50.9	36.1	11.3	0.1	1.6	
457	1 673	Liquid	40.9	31.4	7.2	13.1	7.3	1.30
		Ca ₂ SiO ₄	59.6	35.2	2.9	0.2	2.0	
		Merwinite	51.0	36.4	11.7	0.1	0.8	
505	1 703	Liquid	35.6	28.1	7.8	20.5	7.9	1.26
		Melilite	41.1	24.5	1.8	32.1	0.5	
		spinel	0.3	0.0	26.1	70.0	3.6	
404	1 703	Liquid	40.3	32.0	8.0	9.4	10.0	1.26
		Ca ₂ SiO ₄	59.1	34.5	3.4	0.2	2.6	
		Merwinite	51.2	35.7	11.6	0.1	1.3	
243	1 723	Liquid	33.3	27.7	6.0	25.3	7.8	1.20
		Melilite	40.6	24.1	1.4	33.6	0.3	
		Spinel	0.1	0.0	25.1	70.0	4.8	
263	1 723	Liquid	32.9	27.5	5.2	26.2	8.2	1.20
		Melilite	40.9	24.0	1.3	33.5	0.3	
		Spinel	0.1	0.0	24.2	69.6	6.0	
331	1 723	Liquid	33.6	26.9	5.7	25.7	8.1	1.25
		Melilite	40.9	24.0	1.4	33.3	0.4	
		Spinel	0.1	0.0	25.2	70.1	4.5	
423	1 703	Liquid	34.1	26.0	12.6	16.5	10.9	1.31
		Spinel	0.1	0.1	27.3	70.3	2.2	
		(Mg,Fe ²⁺)O	0.2	0.0	76.7	1.1	22.0	
428	1 723	Liquid	31.6	24.5	12.9	17.5	13.5	1.29
		Spinel	0.3	0.1	26.7	69.9	2.9	
		(Mg,Fe ²⁺)O	0.3	0.1	72.3	1.2	26.2

Fig. 3. Experimentally determined pseudo-ternary section (CaO + SiO₂)–MgO–Al₂O₃ with CaO/SiO₂=1.3 and 5 wt% “FeO”.

Fig. 4. Experimentally determined pseudo-ternary section (CaO + SiO₂)–MgO–Al₂O₃ with CaO/SiO₂=1.3 and 10 wt% “FeO”.

CaO/SiO₂ ratio and “FeO” concentration on the liquidus have to be considered carefully to obtain the locations of the isotherms.

It can be seen from Figs. 3 and 4 that melilite and dicalcium silicate are the stable primary phases at low-MgO region. Liquidus temperatures increase in the melilite primary phase field and decrease in the dicalcium silicate primary phase field with increasing Al₂O₃ concentration. At higher MgO region spinel and merwinite are the major primary phases. When MgO in the liquid is higher than 12–13 wt%, monoxide (Mg, Fe²⁺)O starts to appear and the liquidus temperatures increase rapidly with increasing MgO concentration. The detailed effects of different components on liquidus temperatures will be discussed in the following sections.

FactSage²⁰⁾ is a well-developed thermodynamic model in prediction of slag chemistry. The present experimental results are compared with the predictions calculated by FactSage 6.2²⁰⁾ as shown in Fig. 5. The solid thick lines are experimentally determined boundaries and the solid thin lines are experimentally determined 1 723 K isotherms. The dashed lines are corresponding boundaries and isotherms predicted by FactSage 6.2.²⁰⁾ It can be seen from the figure that FactSage can predicted the same primary phase fields in the composition range investigated. However, the experi-

Fig. 5. Comparisons of boundaries and liquidus temperatures between FactSage 6.2 calculations and present results.

mentally determined spinel primary phase field is smaller and merwinite primary phase field is larger than those predicted by FactSage 6.2. The experimentally determined liquidus temperatures in the melilite and monoxide primary phase fields are close to those predicted by FactSage 6.2. In the primary phase fields of spinel, dicalcium silicate and merwinite, the experimentally determined liquidus temperatures in the melilite and monoxide primary phase fields are significantly lower than those predicted by FactSage 6.2. These comparisons between the experimental results and predictions indicate that the thermodynamic database for this important slag system needs to be further improved. The present data, in particular extensive solid solutions will be used for optimisation of FactSage and other thermodynamic models.

3.2. Effects of “FeO” on Primary Phase Fields and Liquidus Temperatures

The boundaries and 1 723 K liquidus for the sections with 5 and 10 wt% “FeO” are projected on the pseudo-ternary section of (CaO + SiO₂)–MgO–Al₂O₃ with CaO/SiO₂=1.3 as shown in Fig. 6. Previous data on “FeO”-free system³⁾ are also given in the figure for comparison. It can be seen from the figure that presence of up to 10 wt% “FeO” in the slag does not have significant effect on the boundaries of the primary phase fields. The liquidus temperatures in the monoxide primary phase field seems not affected by the “FeO” additions. However, the 1 723 K isotherms in other primary phase fields are significantly affected by the “FeO” addition. Generally the isotherms move to the high-liquidus direction in the primary phase fields of melilite, dicalcium silicate, spinel and merwinite. In the primary phase fields of melilite and spinel, the effects of “FeO” on the liquidus are almost uniform. In the primary phase fields of dicalcium silicate and merwinite, addition of 5 wt% “FeO” has significant effect on the 1 723 K liquidus. Increase of “FeO” from 5 to 10 wt% only slightly move the isotherms in these primary phase fields. This could be explained by the solubility of “FeO” in the solid solutions. It can be seen from Figs. 3 and 4 that in the dicalcium silicate primary phase field, the liquidus temperatures decrease with increasing Al₂O₃ concentration at a given MgO. In another word, Al₂O₃ concentration in the liquid can represent liquidus temperature in the dicalcium silicate primary phase field. Figure 7 shows Al₂O₃ wt% as a function of “FeO” for the 1 723 K liquidus in the dicalcium silicate primary phase field. The

Fig. 6. Effects of "FeO" on primary phase fields and liquidus temperatures in the system $(\text{CaO} + \text{SiO}_2)\text{--Al}_2\text{O}_3\text{--MgO--"FeO"}$ with CaO/SiO_2 ratio of 1.30. "FeO"-free data were from previous paper.³⁾

Fig. 7. Al_2O_3 in liquid and "FeO" in Ca_2SiO_4 as a function of "FeO" (wt%) in liquid in Ca_2SiO_4 primary phase field at 1723 K.

solubilities of "FeO" in the corresponding dicalcium silicate are also shown in the same figure. It can be seen that "FeO" concentrations in the dicalcium silicate increase rapidly at low "FeO" level and then slowly at higher "FeO" level. The decrease of Al_2O_3 concentration in the liquid with increasing "FeO" shows the same trend.

3.3. Application of Pseudo-binary Phase Diagrams

It is much easier for the researchers and engineers to use pseudo-binary phase diagrams to evaluate the effects of slag compositions on liquidus temperatures. Pseudo-binary phase diagrams can be derived from the experimentally determined pseudo-ternaries. **Figures 8(a)** and **8(b)** show liquidus temperatures as a function of $\text{Al}_2\text{O}_3/(\text{CaO} + \text{SiO}_2)$ ratio at fixed MgO 5 and 10 wt%, respectively. In each figure, three sections with 0, 5 and 10 wt% "FeO" are shown for comparison. The data for 0 wt% "FeO" are taken from previous results.³⁾ It can be seen from Fig. 8(a) that, at fixed 5 wt% MgO, melilite and dicalcium silicate are the primary phase fields. The liquidus temperatures decrease in the dicalcium silicate primary phase field and increase in the melilite primary phase field with increasing $\text{Al}_2\text{O}_3/(\text{CaO} + \text{SiO}_2)$ ratio. "FeO" in the slag can decrease the liq-

(a) 5 wt% MgO

(b) 10 wt% MgO

Fig. 8. Pseudo-binary sections of $(\text{CaO} + \text{SiO}_2)\text{--Al}_2\text{O}_3$ with $\text{CaO}/\text{SiO}_2 = 1.3$ at fixed MgO and "FeO", "FeO"-free data were from previous paper.³⁾

uidus temperatures in both melilite and dicalcium silicate primary phase fields. The boundary (minimum liquidus) between melilite and dicalcium silicate primary phase fields moves to lower Al_2O_3 direction when "FeO" in slag is increased. This means that, before "FeO" is fully reduced from the slag, dicalcium silicate is more stable than melilite at low Al_2O_3 . It can be seen from Fig. 8(b) that, more primary phases are present at 10 wt% MgO. At 0 and 5 wt% "FeO", spinel, melilite, merwinite and dicalcium silicate are the primary phase fields. At 10 wt% "FeO", melilite is not stable and three other primary phase fields are present. In general, the liquidus temperatures decrease in the dicalcium silicate and merwinite primary phase fields and increase in the melilite and spinel primary phase fields with increasing $\text{Al}_2\text{O}_3/(\text{CaO} + \text{SiO}_2)$ ratio. Addition of 5 wt% "FeO" can significantly decrease liquidus temperatures. However, increase of "FeO" from 5 to 10 wt% slightly decreases the liquidus temperatures in the dicalcium silicate and merwinite primary phase fields and increases the liquidus temperatures in the spinel primary phase field.

Figures 9(a), **9(b)** and **9(c)** illustrate the liquidus temperature as a function of $\text{MgO}/(\text{CaO} + \text{SiO}_2)$ ratio at fixed Al_2O_3 of 10, 15 and 20 wt% respectively. At 10 wt% Al_2O_3 the liquidus temperatures of "FeO"-free slags are very high and they were not measured. At 15 and 20 wt% Al_2O_3 three sections with 0, 5 and 10 wt% "FeO" are shown for

(a) 10 wt% Al_2O_3 (b) 15 wt% Al_2O_3 (c) 20 wt% Al_2O_3

Fig. 9. Pseudo-binary sections of $(\text{CaO}+\text{SiO}_2)\text{--MgO}$ with $\text{CaO}/\text{SiO}_2=1.3$ at fixed Al_2O_3 and “FeO”, “FeO”-free data were from previous paper.³⁾

comparison. The data for 0 wt% “FeO” are taken from previous results.³⁾ It can be seen from the figures that, at 10 wt% Al_2O_3 , dicalcium silicate is the primary phase field at low- $\text{MgO}/(\text{CaO}+\text{SiO}_2)$ ratio. The liquidus temperatures first increase and then decrease with increasing $\text{MgO}/(\text{CaO}+\text{SiO}_2)$ ratio. Merwinite and monoxide are the primary phases at high- $\text{MgO}/(\text{CaO}+\text{SiO}_2)$ ratio. The liquidus temperatures increase with increasing $\text{MgO}/(\text{CaO}+\text{SiO}_2)$ ratio in these primary phase fields. At 15 and 20 wt% Al_2O_3 , melilite is the primary phase field at low- $\text{MgO}/(\text{CaO}+\text{SiO}_2)$ ratio. The liquidus temperatures of “FeO”-containing slags

(a) 5 wt% “FeO”

(b) 10 wt% “FeO”

Fig. 10. Distribution of MgO between melilite and liquid in comparison with FactSage calculations.

decrease with increasing $\text{MgO}/(\text{CaO}+\text{SiO}_2)$ ratio. At high- $\text{MgO}/(\text{CaO}+\text{SiO}_2)$ ratio, merwinite, monoxide and/or spinel can be the primary phase fields depending on the Al_2O_3 and “FeO” concentrations. The liquidus temperatures in the primary phase fields of merwinite, monoxide and spinel always increase with increasing $\text{MgO}/(\text{CaO}+\text{SiO}_2)$ ratio.

3.4. Distributions of MgO and Al_2O_3 between Liquid and Melilite

One of the advantages of the present technique is to measure the solid compositions together with the corresponding liquid in equilibrium. The data of accurate solid solutions are very important for optimisation of the thermodynamic models. The significant differences between the experimental data and FactSage predictions shown in previous sections have demonstrated that, even well-developed thermodynamic model still needs to be improved to describe the phase equilibria and liquidus temperatures more accurately. It is only possible to be done with large number of accurate experimental data including solid solutions. **Figures 10 and 11** show the distributions of MgO and Al_2O_3 between melilite and liquid, respectively. Not that the CaO/SiO_2 ratio and “FeO” concentration in the liquid are always different in the points shown in the figures. The lines crossed the points represent best-fit of the points with CaO/SiO_2 ratio of 1.3 and nominated “FeO” concentrations. It can be seen from Fig. 10 that MgO in melilite first increases and then decreases slightly with increasing MgO in the liquid. MgO in melilite

Fig. 11. Distribution of Al_2O_3 between melilite and liquid in comparison with FactSage calculations.

decreases with increasing temperature or “FeO”. At the same temperature, the experimentally determined MgO concentrations in melilite are lower than those predicted by FactSage 6.2. On the other hand, it can be seen from Fig. 11 that the distributions of Al_2O_3 between melilite and liquid are complicated which reflects the trends of the isotherms in the melilite primary phase field. Clearly the experimentally determined Al_2O_3 concentrations in the melilite are much higher than those predicted by FactSage 6.2, although the overall trend can be predicted by this computer software.

4. Conclusions

Phase equilibria and liquidus temperatures have been investigated in the system “FeO”–CaO– SiO_2 – Al_2O_3 –MgO with CaO/ SiO_2 ratio 1.3. The liquidus temperatures have been accurately determined in the primary phase fields of

melilite, dicalcium silicate, spinel, merwinite and monoxide to characterise the “FeO”-containing blast furnace slags. Presence of “FeO” in the slag can generally decrease the liquidus temperatures. However, “FeO” can dissolve into all solid phases to form complicated solid solutions and change the stabilities of these solid phases. A series of pseudo-binary phase diagrams can be derived from the pseudo-ternaries to describe the effects of the slag composition on liquidus temperatures. It has been shown that experimental results are significantly different from the FactSage predictions in liquidus temperatures and solid compositions. As the first systematic investigation in the system “FeO”–CaO– SiO_2 – Al_2O_3 –MgO in equilibrium with metallic iron, the experimental data will be used directly for understanding of the complex reactions in blast furnace. They are also invaluable information for optimisation of thermodynamic models.

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