Temperature and composition dependences of viscosity for FeO_x–SiO_2 slag melts under magnetite formation control

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ABSTRACT

Minimization of copper loss into slag melt is an important issue for a sustainable copper smelting process. The viscosity[1-3] of the slag melt affects the phase separation process of Cu-Fe-S matte/FeO_x–SiO_2 slag melts. Viscosity measurements of the slag melts under the conditions of magnetite formation control are desirable as basic data for the smelting process. In this study viscosities of synthesised FeO_x–SiO_2 slag melts with various Fe/SiO_2 mass ratios and Al_2O_3 concentrations and that of a copper slag melt were measured with the control of their oxygen potentials at 1200–1300 °C.

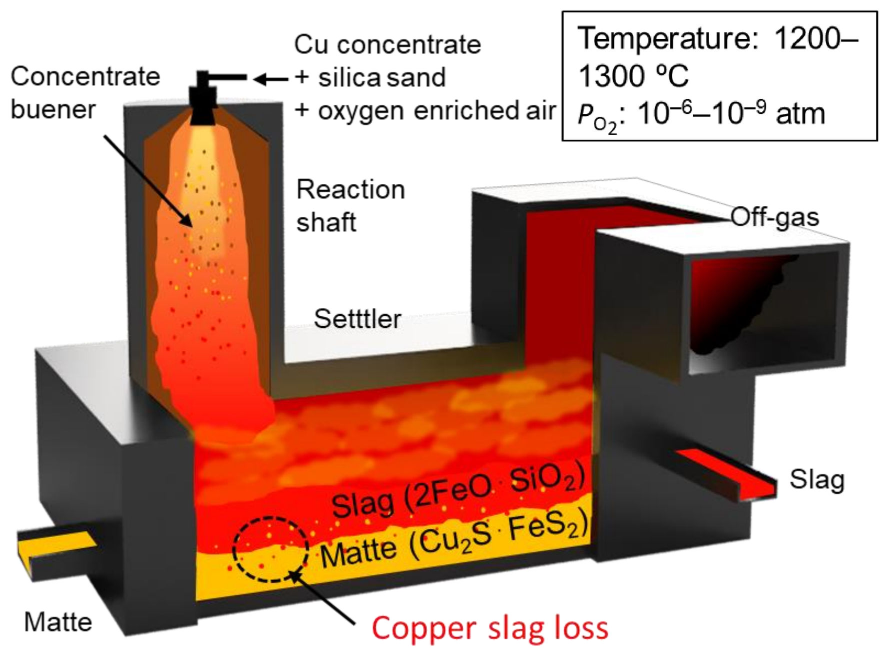
INTRODUCTION

Oxidation Reaction of Copper Concentrate

$CuFeS_2 + SiO_2 + O_2$
$\rightarrow Cu_2S \cdot FeS + 2FeO \cdot SiO_2 + SO_2$

Matte Slag

Separation by difference in specific gravity



Schematic of the Outokumpu smelting furnace

[Problem]
Loss of copper matte particle in oxide slag melt

→ **Viscosity of slag melt affects matte / slag phase separation**

Purpose

- Measurements of oxygen potential of slag melts and determination of melting conditions to minimize magnetite formation
- Evaluation of temperature and composition dependencies of viscosity for copper slag and FeO_x–SiO_2(x=1−1.5) synthesized slag melts

METHODS AND MATERIALS

Measurement of oxygen potential in slag melt

- Sample: Copper slag 100 g
- Temperature: 1250 °C
- Atmosphere : Ar gas flow (P_{O_2} =1.0 × 10^{-6} atm)
- Measuring time: 1 h (Start from 30 min after melting)

The oxygen potential of slag melts was controlled by the selection of crucible materials and the addition of carbon powder for reducing agent.

Viscosity measurements

- Rotating cylinder method
- Copper slag, FeO_x–SiO_2 synthesized slag
- Temperature: 1200–1300 °C
- Atmosphere: Ar (P_{O_2} =1.0 × 10^{-6} atm)
- Handmade high-purity Al_2O_3 crucible

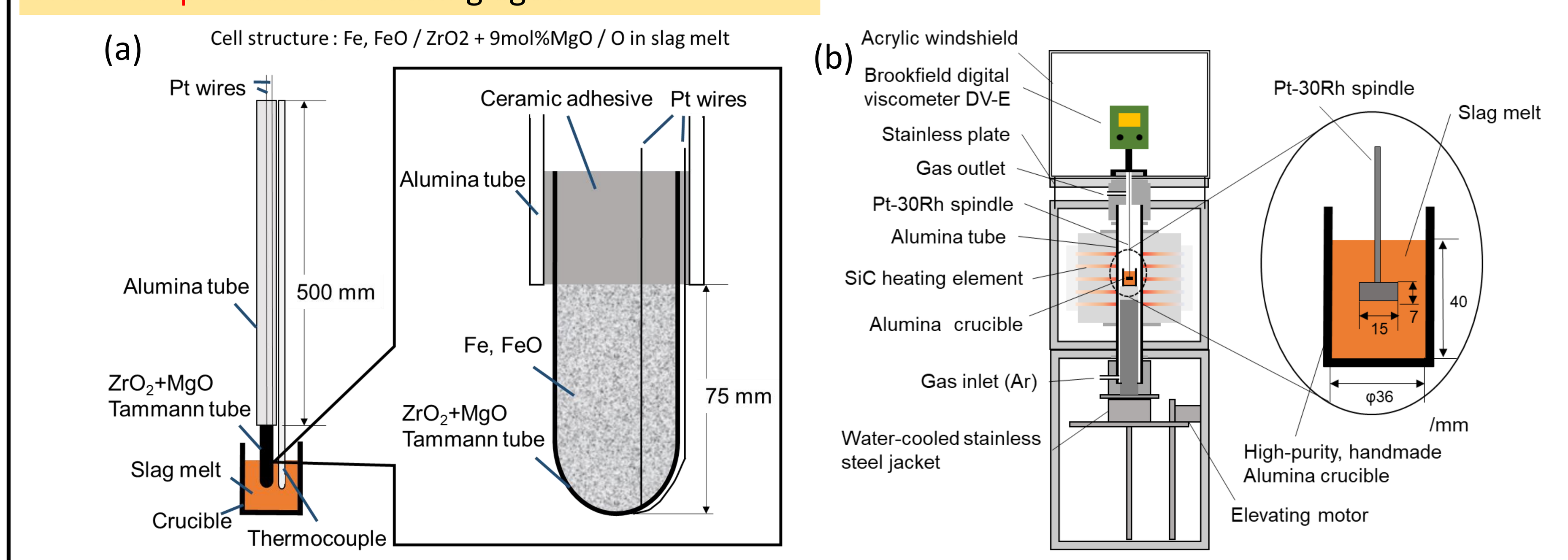


Figure 1: Schematics of (a) zirconia oxygen sensor and (b) viscosity measurement apparatus.

RESULTS

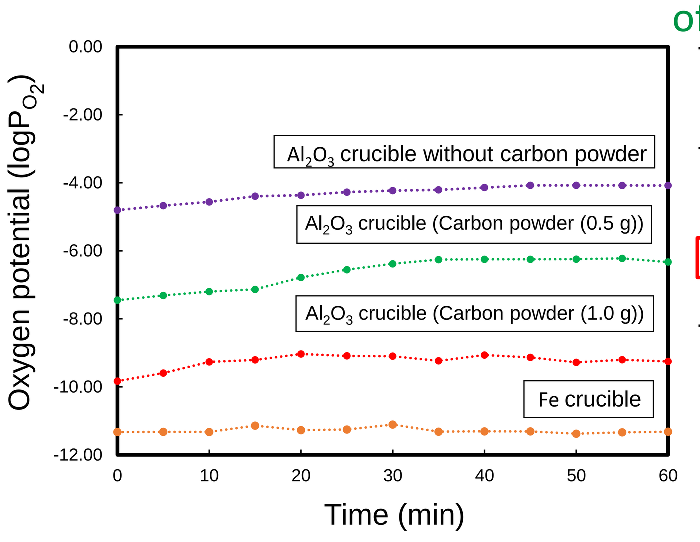
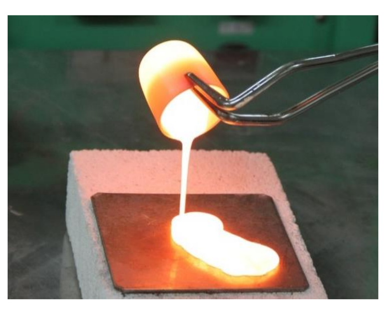


Figure 2: Time dependence of oxygen potential for the copper slag melt.

Table 1: Measured oxygen potentials of the copper slag melt.

Crucible material (Added amount of carbon powder (g))	Average OP value (atm)	Fe^{2+}/Fe_{total} (mass ratio)	
Al_2O_3 (Non)	5.0 × 10^{-5}	0.89	[1]
Al_2O_3 (0.5)	3.2 × 10^{-7}	0.90	[1]
Al_2O_3 (1.0)	4.0 × 10^{-10}	0.98	[2]
Fe (Non)	5.0 × 10^{-12}	0.99	[2]



Casting of homogeneous slag melt

[1] Solid magnetite formation on melt surface

[2] Homogeneous melt without solid formation

Viscosity of the slag melt could be measured by the addition of carbon powder (1.0 g) without solid formation.

Table 2: Composition analysis of copper and FeO_x–SiO_2 synthesized slags by FactSage7.1 using FToxid and FactPS databases.
[1300 °C, P_{O_2}=4.0 × 10^{-10} atm] (mass%)

Slag sample	FeO	Fe_2O_3	SiO_2	Al_2O_3	Others	Total Fe/SiO_2 ratio
FS1	51.3	1.0	39.3	8.4	-	1.0
FS2*	58.4	2.1	38.5	1.1	-	1.2
FS3	58.9	3.0	31.5	6.8	-	1.5
FS4	58.6	3.3	30.6	7.6	-	1.5
FS5	56.0	2.9	30.5	10.6	-	1.5
Copper slag	43.4	0.7	38.1	5.9	11.9	0.9

As for compositions except for FS2, all phases were predicted to be slag liquid phases at 1200–1300 °C, P_{O_2}=4.0 × 10^{-10} atm. (Table 2)

* The precipitation of solid SiO_2 (tridymite) with 1.0 and 3.5 mass% was predicted at 1250 and 1200 °C, respectively.

Decrease of Fe/SiO_2 mass ratio → Viscosity increases (Figure 3)

Increase of Al_2O_3 concentration → Viscosity increases (Figure 4)

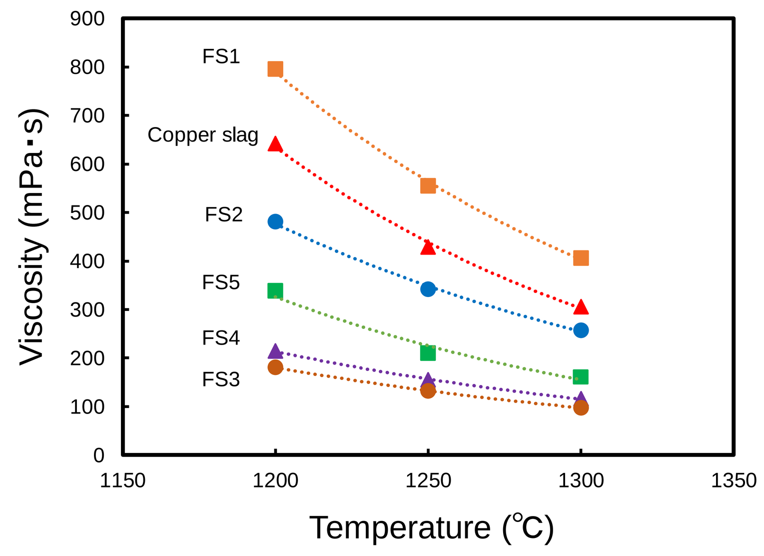


Figure 3: Temperature dependence of viscosity for copper slag and FeO_x–SiO_2 synthesized slag melts.

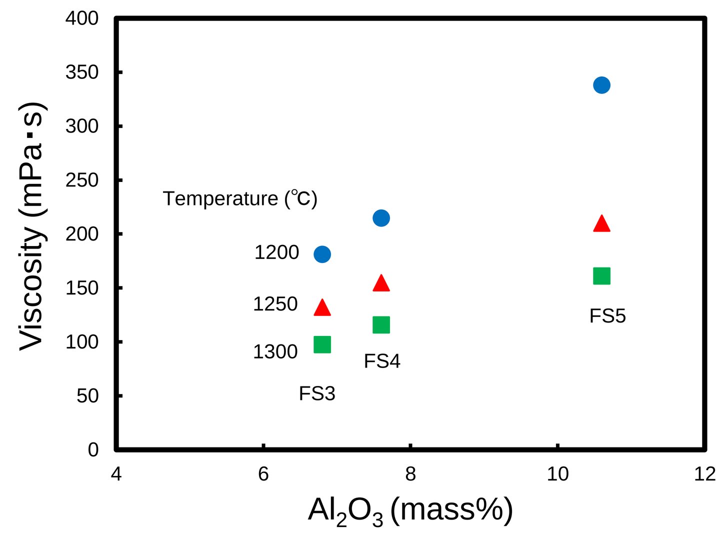
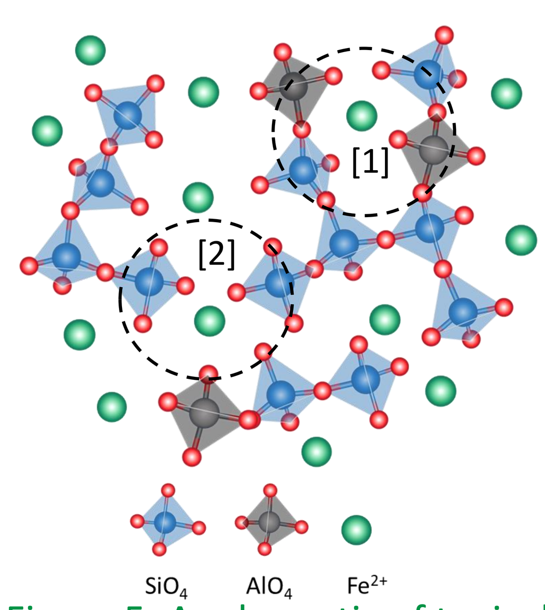
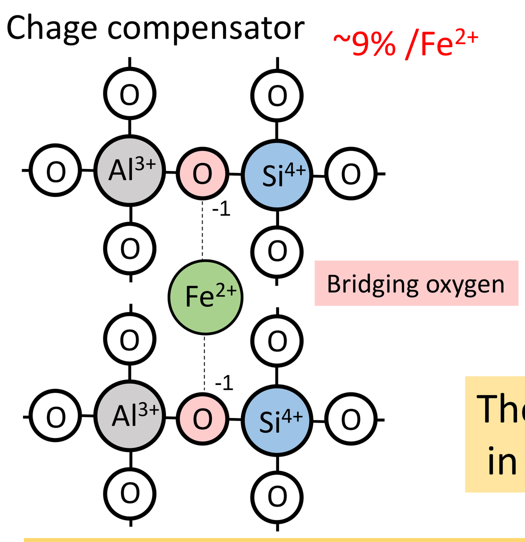
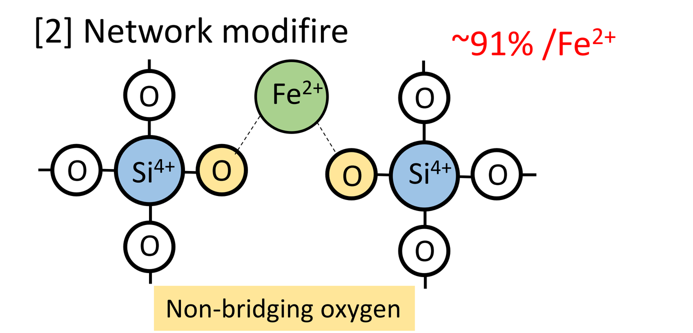


Figure 4: Al_2O_3 concentration dependence of viscosity for copper slag and FeO_x–SiO_2 synthesized slag melts (Fe/SiO_2=1.5).

DISCUSSION







The constituent of FeO has two roles in the slag melts.

Viscosity depends on the polymerization degree of SiO_4 and AlO_4 tetrahedral networks[4] and the free volume[5].

Figure 5: A schematic of typical example, FS3 slag: $58FeO-1.0Fe_2O_3-36SiO_2-5.0Al_2O_3$ (mol%) ([FeO/Al_2O_3] (molar ratio) ›› 1).

CONCLUSIONS

✓Oxygen potentials of slag melts could be controlled under Ar gas flow by the addition of carbon powder to the samples and using the high-purity alumina crucible in the range of 4.0 × 10^{-10} and 5.0 × 10^{-5} atm.

✓Measured viscosity of copper and FeO_x–SiO_2 synthesized slag melts is in the range of 97.5–796 mPa•s at 1200–1300 °C.

✓Viscosity of FeO_x–SiO_2–Al_2O_3 slag melts depends on the polymerization degree of SiO_4 and AlO_4 tetrahedral networks and the free volume. The constituent of FeO has both network modifier (~91%) and charge compensator (~9%) in the slag melts.

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