An equation for the viscosity of molten multicomponent fluxes and slags

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ABSTRACT

An equation has been proposed for predicting viscosities of molten multicomponent fluxes and slags. The equation is expressed in terms of flux or slag components. The equation reproduces experimental viscosity data with good agreement.

INTRODUCTION

Molten fluxes and slags are playing an increasingly important role in high temperature industrial processes as the so-called liquid materials, e.g. metal-refining media, lubricants. The viscosity of network-forming melts, i.e. polymeric melts, such as multicomponent industrial fluxes and slags, is of critical importance since this property has not only a decisive influence on the liquid flow but also a close relationship with the network structure which reflects the states of oxygen atoms in the melts.

In this paper, we have proposed an equation for the prediction of viscosities of molten multicomponent fluxes and slags. The equation is based on the concept of the network parameter introduced by Iida and co-workers in the previous symposium in this series[1].

DERIVATION OF VISCOSITY EQUATION

Network paramerter

The network parameter ϕ is defined as[1]

$$\phi \equiv \log_{10}\left(\frac{\mu}{\mu_0}\right)^2 \qquad (1)$$

where μ is the experimentally obtained viscosity of molten fluxes and slags, μ_0 is the viscosity of non-network-forming melts, i.e. hypothetical slag melts.

The μ_0 values for the hypothetical-multicomponent melts can be computed approximately using the following expressions.

$$\mu_{0i} = 1.8\times10^{-7}\frac{[M_i(T_m)_i]^{1/2}\exp(H_i/RT)}{(V_m)_i^{2/3}\exp[H_i/R(T_m)_i]} \qquad (2)$$

$$H_i \equiv 5.1(T_m)_i^{1.2}$$

$$\mu_0 = \sum_{i=1}^{n} \mu_{0i}\cdot X_i \qquad (3)$$

where M is the formula weight, V_m is the molar volume at the melting point T_m, R is the gas constant , X is the mole fraction, and the subscript i refers to the component.

Values of μ_0 are listed in Table I for the principal constituents of industrial fluxes and slags.

The network parameter, i.e. this demensionless quantity, provides a indication of the extent of network structure, or polymerization, of molten multicomponent fluxes and slags.

Table I Calculated values for the viscosity μ_{0i} (Pa•s) and activation energy Hi($kJmol^{-1}$) of non-network-forming liquids (i.e.hypothetical slag melts).

component	μ_{0i} (1573K)	μ_{0i} (1673K)	μ_{0i} (1773K)	Hi
SiO_2	0.00467	0.00378	0.00313	46.3
Al_2O_3	0.01022	0.00795	0.00635	55.1
MgO	0.05651	0.03966	0.02897	77.5
CaO	0.03303	0.02382	0.01783	71.5
Fe_2O_3	0.00086	0.00080	0.00073	42.6
BaO	0.00999	0.00789	0.00640	51.6
Li_2O	0.00401	0.00324	0.00269	46.3
Na_2O	0.00093	0.00083	0.00075	24.9
K_2O	0.00051	0.00047	0.00038	20.0
CaF_2	0.00259	0.00218	0.00187	37.8

Basicity index

Nakano and co-workers[2] have presented the following dimensionless parameter, called basicity index, as a indicator of functional aspects of multiconponent industrial fluxes and slags.

The basicity index Bi is defined as

$$Bi = \frac{1.53X_{CaO}+1.51X_{MgO}+1.53X_{CaF_2}+1.94X_{Na_2O}+3.55X_{Li_2O}+1.37X_{K_2O}}{1.48X_{SiO_2}+0.098X_{Al_2O_3}} \qquad (4)$$

in which X is the mass percentage. The basicity index gives a measure of depolymerization of the melts. In other words, the reciprocal of the basicity index is a indicator of the extent of network structure of polymeric melts.

Relationship between the network parameter and the basicity index

A simple relationship must exist between the network parameter and the basicity index for network-forming, polymeric melts, since the same network structures are responsible for both. In Figure 1, the network parameter is plotted against the reciprocal of the basicity index for various mold fluxes used in continuous casting of steels[3-8] and a standard reference material (SRM 2)[9] at 1573K. The chemical composition of the standard reference material for high temperature viscosity measurements is given in Table II. Indeed, according to Figure 1, a linear relationship holds approximately between the network parameter calculated from viscosity data and the reciprocal of the basicity index, where a straight line is drawn so as to fit the plot of the SRM 2. The relationship can be written as

$$\phi = -0.792 + \frac{4.62}{Bi} \qquad (5)$$

The values for the slope and the intercept, i.e. 4.62, -0.792, represent the empirical best-fitting factors. Thus, on combaining eqations (1) and (5), we have an equation for the viscosity of molten multicomponent fluxes and slags at 1573K.

$$\mu = 0.402\ \mu_0 \exp\left(\frac{5.33}{Bi}\right) \qquad (6)$$

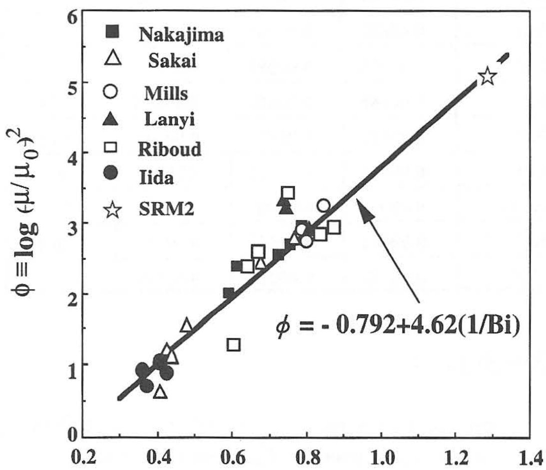

Figure 1. Relationship between the network parameter ϕ and the reciprocal of basicity index 1/Bi at 1573K.

Table II Chemical composition of SRM 2 (mass%).

SiO_2	Al_2O_3	Li_2O	K_2O	Na_2O	MgO	CaO	TiO_2	P_2O_3
63.7	14.4	20.6	0.13	0.40	<0.10	0.40	<0.10	<0.01

COMPARISON OF CALCULATED AND MEASURED VISCOSITIES

In Figure 2, calculated values from equation (6) are compared with experimental data for 18 continuous casting fluxes of different chemical composition[10]. The discrepancies between the experimental values and the calculated values are 20%, as shown in Table III. Agreement with experimental values is very good. Equation (6) allows extrapolations to other multicomponent industrial fluxes and slags. The composition ranges of the continuous casting fluxes studied are given in Table IV.

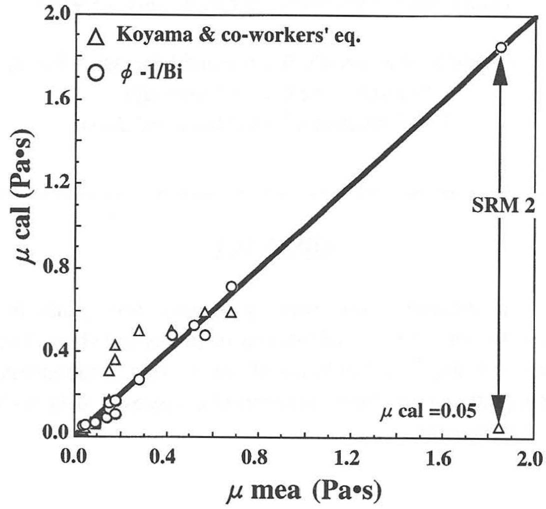

Figure 2. Comparison of measured and calculated values of the viscosity for molten fluxes and slags at 1573K.

Table III Comparison of calculated and measured viscosities at 1573K.

$|(\mu_{mea} - \mu_{cal})| \times 100/\mu_{cal}$

Viscosity range (Pa•s)	ϕ − 1/Bi	Koyama's & co-workers' eq.	
		inclu. SRM 2	exclu. SRM 2
0.03 ~ 2.0	20	228	28

Table IV Composition ranges of continuous casting fluxes used in this study (mass%).

SiO_2	Al_2O_3	CaO	F	Na_2O	MgO	Fe_2O_3	Li_2O
27.9 ~ 44.4	2.8 ~ 6.1	29.5 ~ 48.3	4.1 ~ 10.7	2.6 ~ 13.0	0.6 ~ 5.9	0.1 ~ 1.7	0.0 ~ 9.1

Several expressions have been reported for the prediction of viscosities of multicomponent industrial fluxes and slags. Representative examples are the empirical expressions by Riboud[7], Urbain[11], and Koyama[12]. Calculated results from Koyama and co-workers' equation are also shown in Figure 2 and in Table III, respectively. According to Mills and Keene[13], the discrepancies between the calculated values using Riboud and Urbain equations and the experimental values are of the order of 25 - 30%, which are similar to the experimental uncertainties for the viscosity measurements. Thus, a detailed comparison of predicted and measured viscosities is not particularly fruitful.

CONCLUSIONS

A relationship exists between the network parameter and the basicity index for molten multicomponent fluxes and slags. On the basis of the relationship, an equation has been derived for their viscosity. The equation successfully reproduces experimental viscosity data, and allows extrapolations to other multicomponent industrial fluxes and slags.

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