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Trial Product of Dynamic Co-Axial Cylinder (DCC) Viscometer for Molten Metals, Slags and Salts to 1200°C†

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1. Introduction

Physical properties of molten metals, slags and salts are of interest concerning not only to practical problems in their welding and refining but also to their molten structure from their melting point to high temperature. Formerly, we have been studied experimentally as well as theoretically on their molten state of pure metals and alloys. In particular, viscosities are of considerably importance.

A clearer understanding of molten state can be achieved when precise measurements are available. For these reason, methods of viscosity measurement* have been discussed and a dynamic co-axial cylinder viscometer (DCC Viscometer) has been trially producted. This method of viscosity measurement (DCC Viscometer) is characterized as follows:

1) Viscosity measurements are possible for many kinds of substances (melts) over an extended range of temperature, from their melting point to high temperature.
2) Shear rate can be changed easily by adjusting the moment of inertia of suspended system, i. e. the periodic time of oscillation of the torsion pendulum.
3) The mathematical analysis employed to evalute viscosities from experimental data is drived theoretically.

In the high-temperature field of viscosities of molten metals as well as slags, the DCC Viscometer is probably a new attempt.

2. Theoretical considerations for viscosity measurements by DCC Viscometer

This method of viscosity measurements is that of observing the damping of the oscillation of the inner cylinder (bob) suspended by a torsion fiber into the liquia, due to the viscosity of the liquid. The calculation of viscosities of the liquids from the damping of the oscillations has been discussed and the equation drived by S. Oka and A. Takami[1), 2)]. From measurements of the amplitude and the period of oscillation, viscosity η may be calculated, thus;

$$\eta=\Big\{\frac{R_{out}^2-R_{in}^2}{R_{in}^2 R_{out}^2}\frac{I}{2\pi h}+\frac{\rho R_{in}^2 R_{out}^2}{R_{out}^2-R_{in}^2}\log\frac{R_{out}}{R_{in}} -\frac{\rho R_{in}^3}{4(R_{in}+R_{out})}\Big(3\frac{R_{out}}{R_{in}}+3-\frac{R_{in}}{R_{out}}-\frac{R_{in}^2}{R_{out}^2}\Big)\Big\}\delta \quad (1)$$

where, R_{in} is the radius of the inner cylinder (bob); R_{out}, the radius of the outer cylinder (cup); I, the moment of inertia of the suspended system; h, the length of bob; ρ, the density of liquid; δ, the attenuation constant. Attenuation constant δ is defined;

$$\delta=\frac{\log(|a_m|/|a_{m+2n}|)}{0.4343nT} \quad (2)$$

where, a_m is the maximum amplitude of the first oscillation; a_{m+2n}, the maximum amplitude of the nth oscillation; T, the periodic time of the oscillation.

When the periodic time of the oscillation (T) is a few second or more, the effect of inertia of the liquid can be neglected. Thus, eq (1) is expressed as the following equation.

$$\eta=\frac{R_{out}^2-R_{in}^2}{R_{in}^2 R_{out}^2}\frac{I}{2\pi h}\delta \quad (3)$$

Now, in the eq (1)

$$\frac{R_{out}^2-R_{in}^2}{R_{in}^2 R_{out}^2}\frac{I}{2\pi h}\equiv A$$

$$\frac{R_{in}^2 R_{out}^2}{R_{out}^2-R_{in}^2}\log\frac{R_{out}}{R_{in}}-\frac{R_{in}^3}{4(R_{in}+R_{out})}\times\Big(3\frac{R_{out}}{R_{in}}+3-\frac{R_{in}}{R_{out}}-\frac{R_{in}^2}{R_{out}^2}\Big)\equiv B$$

* Capillary, oscillating-sphere (cylinder), rotational and falling-sphere methods have been used for viscosity measurements of molten metals and slags.

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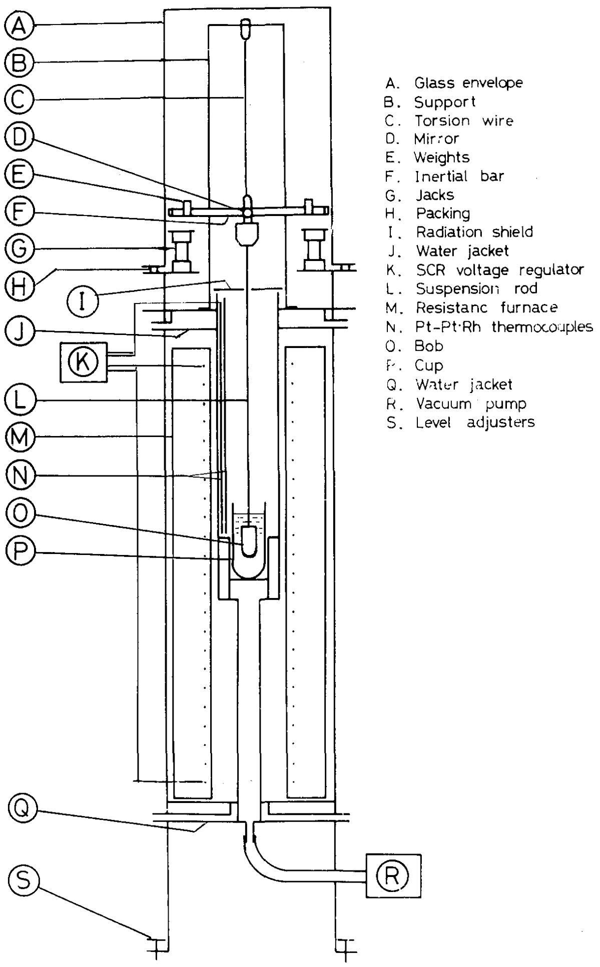

Fig. 1. Cutaway view of dynamic co-axial cylinder viscometer.

A and B are constants for the instrument. Therefore, if the values A and B are obtained experimentally with the standard viscosity sample, viscosities of unknown liquids can be calculated by measuring the attenuation constant (δ) only.

3. Trial product of dynamic co-axial cylinder viscometer for molten metals, slags and salts from their melting point to 1,200°C

The cutaway view of the apparatus in **Fig. 1** shows the suspended system within the high vacuum or inert gas enclosure. The vacuum is maintained at less than $10^{-4}{}_{mm}H_g$ during all definitive measurements. The temperature of the furnace is regulated by means of P. I.D controller. A Pt-Pt·Rh thermocuple is placed adjacent to the outer cylinder. By improving the capacity of furnace, viscosity measurements are possible up to 1,700°C or more.

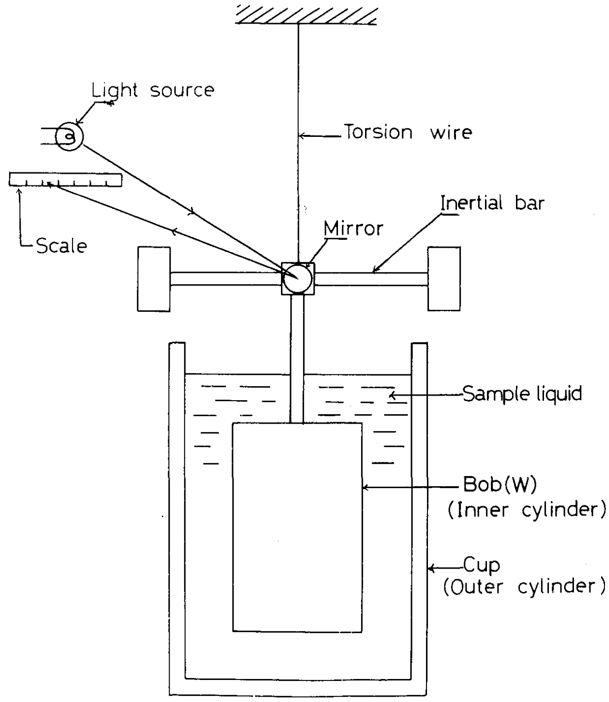

Fig. 2. Schematic diagram of suspension system.

The suspended system is shown in **Fig. 2.** The inner cylinders (bobs) consist of tungsten or fused quartz. The bobs are 11～20 mm dia. and 40～50 mm length and are coated with platinum or alumina (Al_2O_3) according to a kind of melts. Several types of torsion fibers, 0.2～0.25 and 0.3 mm dia. and 20 cm length Mo and W are employed to vary the periodic time of oscillation of the torsion pendulum. Furthermore, to vary the shear rate, the moment of inertia can be easily adjustable. The amplitude of the oscillation is measured by a beam of light reflected from a mirror attached the oscillating system and recorded either by direct reading on a scale, or photographically. The maximum torsion angle of oscillation is 0.1～0.15 radian. The total weight of the suspended system is about 700 gr.

From a metrological standpoint, the most important points are to choose the shear rate, so that the flow of the liquia between bob and cup is laminar, and to determine the end effect.

References

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