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SUBJECT: Low-Temperature Capillary-Tube Viscometer for
Aqueous Thorium Oxide Slurries
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FROM: L. L. Bennett

SUMMARY

As part of the over-all program of investigation of the rheological properties of aqueous thorium oxide slurries, a capillary-tube viscometer was designed for routine determination of shear diagrams of slurries over a temperature range of 30 to 85°C. A particular feature of this viscometer is the vertical orientation of the capillary tube which minimizes the effect on the results obtained with dilute, rapidly-settling slurries.

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LOW-TEMPERATURE CAPILLARY-TUBE VISCOMETER FOR AQUEOUS THORIUM OXIDE SLURRIES

L. L. Bennett

I. Objective

The objective of this design was to provide a viscometer for routine laboratory use in determining shear diagrams of aqueous thorium oxide slurries. A secondary objective was to design a viscometer suitable for general rheologic research including specific studies of end and kinetic energy effect corrections required for accurate determination of slurry properties over a wide range of shear rates.

Specific design criteria were:

1. The slurry holdup must be less than 200 ml. to allow determination of shear diagrams from small quantities of oxide.
2. The capillary tube must be oriented vertically to allow use with dilute, rapidly-settling slurries.
3. The capillary tube must have a L/D ratio of at least 1000 to minimize end-effect influence on the results.
4. The slurry containers must be easily removable to facilitate cleanout and washing between runs with different samples.
5. The whole system must be easily operated and maintained in order to be useful in routine analysis work under laboratory conditions.

II. Viscometer Design Features

The viscometer was designed to accommodate a 200-ml sample of slurry, of which about 150 ml flow through the capillary tube. This small system volume is advantageous since only a small quantity of oxide need be submitted to the laboratory for determination of a shear diagram.

The viscometer tube is oriented vertically to prevent buildup of a sedimentation layer of solids along the tube as can possibly happen in a

horizontal tube at low flow rates. (This allows use of the vertical-tube viscometer at low flow rates with dilute, rapidly-settling slurries.)

The flow rate through the viscometer tube is determined by a system of Auburn^a liquid level control electrodes. Two electrodes, which resemble automobile spark plugs in appearance, are mounted in the head of the upper slurry reservoir. Extending vertically downward from each of these "spark plugs" is a small-diameter probe rod.

With slurry flowing upward from the lower reservoir into the upper receiver, one probe will contact the slurry when it is about $3/8$ in. deep in the pot. This closes an electrical circuit and starts a timer which will continue to run until the slurry rises about 2 inches further and contacts the upper electrode. This contact opens the circuit and stops the timer. Since the volume involved between the probe heights can be calibrated, a direct measurement of flow rate can be obtained.

Capillary diameters selected for this viscometer are 0.063, 0.083, 0.105, and 0.125 inch. Initial tests will be conducted with tubes having a L/D ratio of 1000.

The upper and lower slurry containers are constructed of 2-inch and 2-1/2-inch schedule 40 stainless steel pipe, respectively. Stainless steel is also used for all machined parts which will be in contact with slurry.

The bearings and seals for the agitator shafts are housed as a unit and attached to the slurry containers by means of male-female type flanges. These flanges are closed by quick-opening toggle clamps which allow rapid dismantling for cleaning.

Agitator configuration was investigated by running tests with various agitators in a plastic mock-up of the lower slurry reservoir. Calcium carbonate in water was used as the test slurry. Agitator configurations tested were:

1. Right-hand helix to lift the slurry;
2. A lifting propeller topped by a flat-bladed paddle;
3. A downward-thrusting propeller topped by a flat-bladed paddle.

Results of tests with these agitators at various speeds indicated that the best combination is as follows:

1. Configuration No. 3;
2. Speed: 100-200 RPM;
3. Distance off bottom: about $1/8$ in.

These specifications are being followed in the fabrication of the viscometer agitators.

The slurry is heated by an electrical band heater clamped around the lower reservoir. Temperature is measured from a thermocouple which is immersed in the slurry and controlled by means of a controller which interrupts power to the heater. The capillary tube is heated by hot water flowing through a water jacket around the tube.

III. Viscometer Design Calculations

A schematic diagram of the viscometer system is shown in Fig. 1. Calculations used to determine dimensions are given below; equations were obtained from Reference 1.

An allowable working stress of 12,000 psi was used for both 316 and 347 stainless steel at temperatures below 100°C. Maximum operating pressure was taken as 200 psi (available pressure on low pressure building air supply is 90 psi).

1. Upper and Lower Reservoir Wall Thickness

The upper and lower reservoirs are made from 2-in. and 2-1/2-in. sch. 40, type 347 stainless steel seamless pipe, respectively.

2. Bottom Plate of Reservoirs

For uniformly loaded circular plate supported at edge

$$S_b = \frac{3W}{8\pi mt^2} (3m + 1)$$

$$\text{where } W = \pi r^2 p$$

$$m = \frac{1}{\text{Poisson's ratio}} = \frac{1}{0.26}$$

from which

$$S_b = \frac{3pr^2}{8t^2/.26} \left(\frac{3}{0.26} + 1 \right) = 1.23 pr^2/t^2$$

$$\text{or } t = 1.23 pr^2/S_b$$

$$p = 200 \text{ psi}$$

$$r = 1.235" \text{ (bottom pot)}$$

$$t = (1.23)(200)(1.235)^2/12,000$$

$$S_b = 12,000 \text{ psi}$$

which gives

$$t = 0.177" \text{ (use } t = 0.250")$$

3. Lower Reservoir Flanges

Flanges were calculated as circular flat plates with a central rigid portion and with a concentrated load at outer edge. (Assume 3 clamps will be used.)

a. Force per clamp = $\frac{1}{3} F_T$

$F_T = \pi r^2 p$ where r = radius of gasket face = 1.875"

$F_c = \frac{1}{3} F_T = \frac{\pi \times 1.875^2 \times 200}{3}$

$F_c = 736 \text{ lbs.}$

$S_{\max} = \beta \frac{F_c}{t^2}$ where $\beta = 5.20$ (ref. 1)

$t^2 = \beta \frac{F_c}{S} = \frac{5.20 \times 736}{12000} = 0.318 \text{ inch}$

$t = 0.564" \text{ (use } t = 5/8")$

4. Upper Reservoir Flanges

$F_c = \frac{1}{3} \times \pi \times (1.594)^2 \times 200 = 532 \text{ lbs.}$

$S_{\max} = \beta \frac{F_c}{t^2}$ $\beta = 5.50$ (ref.1)

$t^2 = \frac{5.50 \times 532}{12000} = 0.243$

$t = 0.493" \text{ (use } t = 5/8")$

Flange dimensions were checked by calculating as a cantilever built in at the root and loaded with a concentrated load at the edge. In each case the dimensions agreed with the values obtained above.

5. Clamps for Upper and Lower Reservoir

Based on the calculations involved in designing the flanges, the clamps selected were De-Sta-Co,⁶ Model 435-P, toggle-action clamps.

b. Detroit Stamping Company, Detroit, Michigan.

REFERENCES

1. R. J. Roark, Formulas for Stress and Strain, McGraw-Hill, New York, 1954.

APPENDIX A

LOW-TEMPERATURE VERTICAL-TUBE VISCOMETER

LIST OF DRAWINGS

<u>Number</u>	<u>Title</u>
TD-C-3455	Lower Slurry Reservoir Details
TD-C-3456	Lower Bearing and Seal Assembly
TD-C-3457	Details of Male Flange and Bearing Housing for Lower Reservoir
TD-C-3458	Details of Fittings for Stirrer Bearings and Seal
TD-A-3459	Mixer Shaft Details
TD-A-3460	Air and Water Tubing Leads
TD-C-3461	Upper Slurry Reservoir Details
TD-C-3462	Upper Reservoir Head Assembly
TD-C-3463	Details of Parts for Upper Reservoir Head
TD-C-3464	Upper Bearing Housing Details
TD-A-3465	Electrode Socket
TD-A-3466	Baffle
TD-C-3474	Viscometer Tube Assembly
TD-C-3493	Upper Reservoir Bracket
TD-A-3497	Agitator
TD-A-3498	Agitator Shaft Union

FIGURE 1. LOW-TEMPERATURE VERTICAL-TUBE VISCOMETER
SCHEMATIC FLOW DIAGRAM

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