THE ORIFICE VISCOMETER: A NEW TECHNIQUE FOR MEASURING RHEOLOGICAL PROPERTIES OF MASSECUITES AND MOLASSES

S.M.R. Maudarbocus
Mauritius Sugar Industry Research Institute

ABSTRACT

A simple, cheap and reliable method of measuring rheological properties of massecuites and molasses is described. This involves measuring the head loss across an orifice for a given flow rate.

Comparisons between results obtained with the orifice viscometer and a pipeline viscometer are presented.

INTRODUCTION

The measurement of the rheological properties of massecuites and molasses is important not only for research purposes but also in the design of flow systems, e.g. sizing of pipes, specification of pumps etc. and in the control of the crystallization process. While standard techniques are available for measuring the viscosity of molasses, very few lend themselves to the measurement of massecuite viscosities. At the 16th and 17th ICUMSA sessions, the rotating cylinder method had been recommended as a standard technique for measuring viscosity of molasses. The lack of suitable techniques for massecuites has been emphasized. The presence of the solid phase in the massecuites limits the use of conventional measuring techniques. The Brookfield viscometer, for example, is unsuitable for massecuites because of the tendency for crystals to segregate in the viscometer cup. Other methods have been criticized by several workers as being unsatisfactory.

In this spectrum, the 16th ICUMSA session has recommended the study of flow properties of massecuites to develop a standard measuring technique. Following these recommendations, work was carried out by Ozer and White on a pipeline viscometer. Basically, this involves extruding massecuites from a large diameter reservoir through a small diameter tube of known length and calculating the pressure drop across the tube. Following satisfactory reports on this technique, Moritsugu recommended that the pipe flow method be further studied to develop it as a standard measuring technique. This method is suitable for molasses as well.

Moreover, tests carried out on the flow of viscous materials through orifices indicated that the orifice flow method could well be used as a viscosity measuring technique and an apparatus incorporating a single orifice could be constructed as a simple viscometer for extremely viscous materials. Its suitability for measuring rheological properties of massecuites and molasses had to be studied.

Before describing the orifice flow method the factors describing the flow characteristics of massecuites and molasses are discussed.
Factors characterizing rheological properties

For Newtonian fluids e.g. water, there is a direct relationship between the shear stress, \( \tau \), and the shear rate, \( \dot{\gamma} \):

\[ \tau = \mu \dot{\gamma} \]  
\[(1)\]

where \( \mu \) is the viscosity, a constant independent of \( \dot{\gamma} \) and dependent only on temperature. At a given temperature, a single determination of the shear stress at a fixed shear rate is sufficient to determine the viscosity.

This, however, does not apply to non-Newtonian fluids e.g. molasses and massecuites, where a non-linear relationship exists, and is expressed as a power law equation

\[ \tau = K \dot{\gamma}^n \]  
\[(2)\]

where \( K \) and \( n \) are constants.

The combination of equation (1) and (2) defines an apparent viscosity

\[ \mu_a = K \dot{\gamma}^{n-1} \]  
\[(3)\]

This apparent viscosity has no meaning unless the shear rate and the temperature are both specified. The shear rate is given approximately by

\[ \dot{\gamma} = \frac{8V}{D} \]  
\[(4)\]

a simplification of the Rabinowitsch-Mooney Equation, \( V \) being the velocity of flow and \( D \) the diameter.

The rheological properties of massecuites and molasses can thus be described by an apparent viscosity at a given shear rate and given temperature.

The orifice-flow method

The basis of this method is that under creeping (laminar) flow the head loss across an orifice depends on (a) the fluid viscosity, (b) the flow rate and (c) the orifice area.

In the creeping flow regime dimensional analysis shows that the flow across an orifice can be characterized by a constant dimensionless number, the Lagrange number, defined by:

\[ L_\alpha = \frac{\Delta h D}{\nu \mu^{1/3}} \]  
\[(5)\]

where \( \Delta h \) is the head loss across the orifice, \( D \) the orifice diameter, \( \nu \) the viscosity through the orifice and \( \mu \) the viscosity of the fluid. This constant number has a value of 20 as demonstrated by Maudarbocus and White. Later tests with improved measuring techniques gave a value of 19. The criterion whether laminar flow occurs is given by the Reynolds number being less than 10.

By measuring the pressure drop and the flow across an orifice, the viscosity at a given temperature can be calculated from equation (5), this viscosity being the apparent value pertaining to a shear rate given by equation (4).
EXPERIMENTAL PROCEDURE

The orifice viscometer

The apparatus (Fig. 1) consisted of an open rectangular perspex box, 24 m wide, .48 m long and .30 m deep. A thin but rigid metal insert is fitted into a close fitting slot across the middle of the box to provide an orifice of appropriate size.

The material was circulated through the orifice until steady state was reached as shown by the constancy of the levels on both sides of the orifice. At steady state the levels were measured with a sharpened probe attached to a Vernier scale. The probe was adjusted until it just touched the surface of flowing liquid. The levels were measured as close as possible to the orifice plate. Flow rates were measured by weighing the quantity of fluid of material discharging in a given time. All measurements were made under gravity and were carried out at constant temperature. Orifices of 3 and 5 cm were used.

A pipeline viscometer was also used to determine the apparent viscosity. The material was forced under pressure from a large reservoir (13 cm diameter) through a small tube (0.72 cm diameter) with a length to diameter ratio of 30. At steady state condition the material was collected in a given time at a fixed air pressure. This was repeated at different air pressures.

RESULTS AND DISCUSSION

Fig. 2 and Fig. 3 give the apparent viscosity values at different shear rates for particular samples of massecuites and molasses, respectively. Included in these figures are results obtained with the pipeline viscometer. As expected, the apparent viscosity decreased thus confirming the non-Newtonian behavior.

Compared with the pipeline flow method, lower shear rate value were obtained with the orifice viscometer. Extrapolation from higher shear rates to lower values or vice versa gave concording viscosities between the two methods.

Table 1 compares the orifice and pipeline viscometers for different samples at the same temperature and same shear rate. The viscosities obtained from both methods were extrapolated to the same shear rate so that they could be compared. A statistical analysis shows that the difference between the orifice and pipeline viscometers is not significant at 95% confidence limits.

| TABLE 1. Comparison of orifice and pipeline viscometers at a shear rate of 10 s⁻¹ |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
|                                           | Molasses                      | Masssecuites                        |
|                                           | Sample 1 (21°C)  Pa s | Sample 2 (17°C)  Pa s  | Sample 3 (20°C)  Pa s  | Sample 4 (18°C)  Pa s  |
| Orifice viscometer                      | 32                           | 85                             | 420               | 325               |
| Pipeline viscometer                    | 29                           | 75                             | 425               | 400               |
The location of the orifice with respect to the container walls might be expected to have an effect on the results. Except where there is obvious obstructions, however, the effect appears to be very small. Moving the orifice closer or further from the bottom of the apparatus had no detectable effects on the results.

These results confirm that the orifice viscometer is a reliable instrument for measuring rheological properties of massecuites and molasses. This technique is simple, cheap and efficient. Its use for measuring actual flow characteristics of massecuites is particularly interesting as it bridges a gap in the techniques available for rheological property measurement of massecuites. It is also conveniently geared to continuous systems. Such a device incorporated in a continuous crystallization system would be a valuable tool for control purposes.

**FIGURE 1. Orifice Viscometer**
Figure 3. Apparent viscosity of molasses.

Shear Rate vs. 1/Pa
CONCLUSION

The orifice viscometer is a simple and cheap method for measuring rheological properties of both massecuites and molasses. It is particularly geared to continuous systems.

This viscometer gives results which are consistent with those obtained with a pipeline viscometer.

REFERENCES

2. ICUMSA. Proc. 17th Session, in press.

EL VISCOMETRO DE ORIFICIO: UNA NUEVA TECNICA PARA MEDIR LAS PROPIEDADES REOLOGICAS DE MASACOCIDAS Y MIELES.

S.M.R. Maudarbocus

RESUMEN

Se describe un metodo simple, barato y confiable para la medicion de las propiedades reologicas de masacocidas y mieles. El metodo consiste en la medicion de la perdida de carga a traves de un orificio para un regimen de flujo dado.

Se presenta la comparacion entre los resultados obtenidos con un viscometro de orificio y un viscometro de tuberia.