Time Variations and Calibration of a Screw Type Process Rheometer

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Abstract:
The present article describes and analyzes different calibration methods for a screw type process rheometer, Searle type, having a die hole at the downstream of a barrel. The work also quantifies the effect of time dependent flows due to the screw on the measurement performance. Time variations in torque and pressure become more notorious at increased resistances to flow (higher fluid viscosities and smaller die diameters). Screw speeds seem to do not affect these variations. Shear stress in the system is related to pressure and torque, and by using any of them, is possible to predict an average viscosity. Similar prediction errors were found when using torque or pressure. A section of practical applications is added to understand the use of a screw type process rheometer better.

Zusammenfassung:
Der vorliegende Artikel untersucht und beschreibt unterschiedliche Kalibrationsmethoden für ein Prozess-Schneckenrheometer nach dem Searle-Prinzip, das eine Lochdüse am Zylinderauslass hat. Ausserdem wurde in dieser Arbeit der Effekt der Zeitabhängigkeit des Flusses aufgrund der rotierenden Schnecke zur Messleistung. Zeitschwankungen in Drehkraft und Druck werden deutlicher, wenn der Widerstand zum Fluss erhöht wird (durch Flüssigkeiten höhrer Viskosität und einen geringeren Düsendurchmesser). Die Scherspannung in einem System ist abhängig von Druck und Drehmoment und durch Messung eines der beiden Parameter lässt sich die durchschnittliche Viskosität vorhersagen. Der Prädiktionsfehler für die Viskosität war für Druck und Drehmoment ähnlich. Ein Abschnitt über praktische Anwendungen für diese Art Prozess-Schneckenrheometer wurde dem Artikel hinzugefügt, um dessen Nutzung besser zu veranschaulichen.

Résumé:
Cet article décrit et analyse différentes méthodes de calibration pour un rhéomètre de type procédé-vis, type Searle, qui possède une filière en forme de trou monté au bout d'un canon. L'étude quantifie également l'effet des écoulements transitoires associés à la vis sur la performance de la mesure. Les variations temporelles du couple et de la pression deviennent plus prononcés lorsque la résistance à l'écoulement est accentuée (fluides de viscosité plus élevée, et diamètre de filière plus petit). Les vitesses de la vis ne semblent pas affecter ces variations. La contrainte de cisaillement dans ce système est reliée à la pression et au couple, et en utilisant l'une ou l'autre, il est possible de prédire une viscosité moyenne. Des erreurs de prédiction similaires sont trouvées que ce soit en utilisant le couple ou la pression. Un paragraphe décrivant des applications pratiques est ajouté afin de mieux comprendre l'utilité de ce type de rhéomètre.

Key words: rheometer, viscometer, process, viscosity, measurement method, time variation

1 INTRODUCTION

Process rheometers, process viscometers and consistency analyzers, are normally used to keep steady the rheological properties of the feed during processing. Process rheometers and viscometers are normally used to measure the viscosity of a representative portion of the product stream. Consistency analyzer are used to measure the consistency, that is expressed as a percentage by dividing the mass of a solid material by the total mass of a wet sample, most of them measure mechanically the resistance to deformation, and thus is related to apparent viscosity. Consistency analyzers are used for wood pulp, dough, tomato paste, paint, gelatin or drilling mud [1]. Some of the industrial viscometers used by the process industry are: differential pressure type capillary viscometers, back pressure type, falling-piston viscometer, falling slug or falling ball viscometers, float viscometers, oscillating

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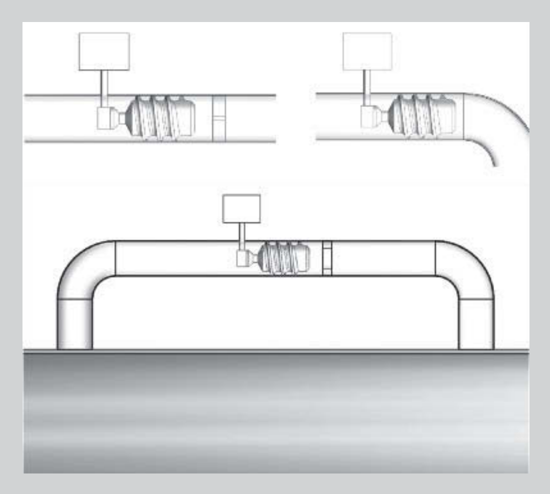

Figure 9: Possible installation for a screw type process rheometer to measure fluids from a product stream.

The differences in torque and pressure among repeated tests leading to the described errors, may partly be due to small temperature differences between the repetitions since the viscosity of Polybuthene-1 is very sensitive to temperature. In the lower temperature range of our experiments, changes in a fraction of a degree Celsius, can lead to changes in several viscosity units (Pa·s). Previously, it was commented that slow temperature fluctuations were not displayed in the spectral plots because they focused on higher frequencies. Schüller and Salas-Bringas [16] found even larger errors to the ones seen in this research when using a Physica UDS200 rheometer with the same fluid, Polybuthene-1, during rapid transient tests using plate-plate measuring system. This is caused by a temperature gradient in the fluid when is only heated by a Peltier plate at the bottom.

4 PRACTICAL APPLICATIONS

Example of possible process installations of the screw type process rheometer are shown in Figure 9. On the top left side of Figure 9, it is shown how the rheometer could be positioned in a straight pipe having a restriction. This set up can be a good solution when measuring low viscosity fluids. On the top right side of Figure 9 the screw is positioned before a bend, this figure does not include a restriction to show that any natural pressure loss might be enough to generate a sufficient pressure or torque reading. At the bottom of Figure 9 it is represented a bypass that can be used to extract part of the fluid from the main process stream. In this last alternative, a smaller restriction is drawn to shown how the set up can vary according to the specific requirements. For a practical use of the rheometer by a control unit (e.g. PLC, PID, etc), viscosity (Pa·s) or consistency (%) units are not important, but an electrical signal that can indicate the extent of torque or pressure, in this way the process will be regulated by the control unit to keep the electrical signal from the rheometer constant. However viscosity and consistency values are important to certify quality or traceability.

For cases requiring viscosity measurements using Non-Newtonian fluids, an average or apparent viscosity can be used since different strain rates are present in the screw, as it is similarly obtained today from mixer, parallel plate and bob type of rheometers. An average viscosity or sometimes presented as equivalent Newtonian viscosity [17] can be obtained by following any of the calibration procedures described in this research. In some fluids, elongational flow might be present at the die. To eliminate this type of flow, it is been shown on literature that the entry angle of a die can be manipulated to produce pure shear flow [18]. It is possible to encounter offsets for viscosity using these calibration methods based on N450000 standard for fluids having yield stress. For example, the velocity profile in capillary flow (die region) between a fluid with and without yield stress are different [19], and therefore different shear stresses (linked to torque and pressure) are present. Also it has been reported for Couette flow that a Newtonian assumption for the wall shear rate can lead to errors, especially when increasing the gap size and yield stress [20, 21]. Traditionally the complex flows occurring between a rotating screw and a stationary barrel has been approximated to Couette flow [6]. However, for process control applications where a steady consistency of the fluid is the goal, this should not present any obstacle. Yield stress can be estimated by performing a stress relaxation test by stopping the process rheometer after running at constant speed. The residual pressure difference between the inlet and exit of the restriction must be registered. For circular channels the following equation can be used: $\tau_o = \Delta P_{Min} R/(2L)$, where τ_o is the yield stress, ΔP_{Min} residual pressure, R channel radius and L channel length [22, 23].

5 CONCLUSIONS

Time variations in pressure and torque seem to be mainly caused by time dependent flows produced by the non-symmetric geometry of the screw. These variations can become more notorious (e.g. increased amplitude of torque and pressure oscillations) at higher resistances to flow produced by either an increased viscosity or to a lesser extent by reductions in die diameter. The most notorious fluctuations occur at a half, and on each shaft revolution. The influence of different running speeds does not seem to affect the variations in amplitudes of torque and pressure. The range of viscosities that can be predicted in this rheometer can be widened by changing and selecting different die sizes. It is possible to predict viscosity using different dies by using prediction models based on calibration experiments. The RMSEP (± Pa·s) based on the prediction models using Slope *a*, *MA* and Slope *b* were not significantly different ($p < 0.05$). By using Slope *a* and Slope *b*, it was not possible to successfully model the data at low die restrictions (5.5 mm). The models based on *PA* gives the significantly ($p < 0.05$) smallest RMSEP (± Pa·s), except for the model using the lowest die restriction (5.5 mm), which was not significantly different to the Slope *a*. Because of the complex flows and the different shear rates present in the rheometer, it is not possible to compute a unique shear viscosity when Non-Newtonian fluids are used. However, is possible to obtain an average or representative viscosity using the prediction models presented in this research. Keeping the same degree of filling will be mandatory to use the same prediction models in the future.

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