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TECHNICAL COMMUNICATION

A Portable Rotational Viscometer for Field and Laboratory Analysis of Cohesive Sediment Suspensions

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INTRODUCTION AND PURPOSE

In studies of the erosion, transport, and deposition of dense near bottom suspensions of fine-grained cohesive sediment, it is often useful to ascertain the particular form of rheological behavior which may be exhibited by the suspension as it responds to the stresses imposed upon it by its environment. These forms of behavior may be time-dependent or independent, Newtonian or non-Newtonian and may show some or all forms of rheological behavior during an analysis, depending upon environmental conditions. For a treatment of suspension rheology, see VAN WAZER *et al.*, (1963) and VAN OLPHEN, (1977). The purpose of this note is to describe in some detail an instrument which has been used to make observations of these phenomena, to discuss its usefulness for laboratory and field analyses, and to suggest that it be considered an important tool for understanding and predicting the dynamic behavior of such material.

THE INSTRUMENT

The instrument is the hand-held Brookfield Rotational Viscometer, manufactured by the Brookfield Engineering Laboratories, Inc., Stoughton, Massachusetts 02072, USA. Various models are available encompassing rotational speeds from 0.3 to 200 RPM and torque springs from 673.7 to 57,496.0 dyne-centimeters. Two instrument designs are available: analog (dial-reading) and digital. However, both represent the same basic types and use the same accessories. The dial-reading types are least expensive, are more suitable for situations where samples are to be tested over relatively short times, and do not retain permanent records of rheological behavior, *e.g.*, they have no recording capability. Digital instruments, on the other hand, are more expensive, record processes continuously, but cannot be hand-held during use. Consequently, it is unlikely that a digital instrument would be useful in the field or on board ship.

The instrument rotates a spindle, either disc-shaped or cylindrical (bob) in a concentric container of fluid (cup), or in an effectively infinite reservoir of fluid. The spindle is rotated at constant angular velocity and the torque exerted on the spindle by the fluid is shown as a dial reading. This reading, when multiplied by the spring constant for the instrument being used is the shear stress at that particular angular velocity.

The Brookfield viscometer has been criticized because the design of the standard disc-type spindles is undesirable for testing non-Newtonian fluids due to significant edge effects and attempts have been made to convert the disc-spindle data to absolute viscosity values (Mitschka, 1982). Another problem is that when using cylindrical spindles, often the gap between the spindle and the container is very large, creating a non-linear shear field across the gap. However, the company has responded to this criticism by designing the "Small Sample Adaptor" and the "UL Adaptor." Consequently, it is now possible to analyze non-Newtonian fluids with precisely machined, mathematically well-characterized coaxial cylinder geometry.

Attachments

The UL Adaptor consists of a stainless steel, coaxial cylinder (cup and bob) arrangement, possessing a narrow gap (2.47 mm), and cup diameter to bob diameter ratio of 1.098. It was specifically designed to provide greater sensitivity for low viscosity fluids, the minimum measurable viscosity depending upon the viscometer model. During analysis, the bob rotates within the cup (Searles-type), the torque required to rotate the bob is measured by an internal calibrated spring and is the shear stress required to cause flow of the sample at that particular rate of rotation. The coaxial cylinder geometry and dimensions of the UL Adaptor allow shear rate determinations to be made with an accuracy of less than 1% (VAN WAZER *et al.,* 1963). This Adaptor is especially useful for analyzing naturally occurring sedimentary suspensions due to the width of the gap (2.47 mm) inasmuch as VAN WAZER *et al.,* (1963) suggests that the diameter of the largest particles in the suspension be no greater than 10% of the width of the gap. Measurements can be made on approximately 25 ml of suspension placed directly in the cup. After analysis, the sample may be poured from the cup and used to determine water content. If measurements are to be made directly in a flume or the top of a box core, the plastic cap at the base of the cup may be removed, the adaptor placed in the suspension, the viscometer leveled by means of the attached bubble levels, and the analysis performed with the least possible disturbance. Calculations using the measured shear stresses and absolute shear rates result in 'apparent' viscosity values for the non-Newtonian suspensions. These values can then be plotted against other parameters, *e.g.*, shear rate, suspension density, to reveal other relationships.

The Small Sample Adapter is a jacketed, coaxial cylinder attachment that is available for use with all Brookfield viscometer models. It can measure viscosities ranging from 5 cPs to 10,000,000 cPs and spans the range of shear rate from 0.066 to 93.0 s^{-1}. The jacketed design makes it possible to connect the attachment to a temperature controlled water bath to assess thermal effects on viscosity and flow behavior.

Yield Stress Measurements

Yield stress appears to be a parameter which is important in controlling erosion and resuspension in muddy estuarine and coastal environments (McCAVE, 1984; NICHOLS and BIGGS, 1985). The yield stress of a non-Newtonian suspension is the minimum shear stress corresponding to the first evidence of flow, *e.g.*, the value of the shear stress at zero velocity gradient. Yield stress determinations are most easily and accurately made with cylindrical spindles rotating in suitable cups (after determining the end effect for each spindle under the same conditions). These measurements cannot easily be made with the Brookfield rotational viscometers inasmuch as a significant number of very low shear rate tests are required to provide sufficient data within the non-linear portion of rheograms to enable extrapolation to a zero shear rate for determination of the critical shear stress at which the suspension begins to flow. However, several other techniques are available which provide reasonable approximations of this parameter. One solution is to treat the suspension as a Bingham plastic substance. By projecting the straightline segment of the shear stress—shear rate curve to intersect the shear stress axis, the Bingham plastic yield stress can be determined. Numerous investigations of clay-water suspensions, both from the natural environment (MIGNIOT, 1968; KRONE, 1963, 1986; WELLS and COLEMAN, 1981) as well as from laboratory preparations of various clay minerals (MICHAELS and BOGER, 1962; PAZWASH and ROBERTSON, 1971; WILLIAMS, 1986) have documented the Bingham plastic character of such suspensions, thus providing a rational basis for using the Bingham yield stress as a defining parameter. A second solution involves shearing the material at a low and constant shear rate to measure the stress-time response of the material. The shear stress corresponding to the first evidence of plastic flow can be interpreted as a yield stress. NGUYEN and BOGER (1983) used a shear vane which was rotated at a low and constant rate until the maximum torque value was obtained. JAMES *et al.*, (1987) using a Weissenberg (R17) Rheogoniometer sheared illite suspensions at exceptionally low shear rates (6.63×10^{-3} s^{-1}) and recorded a peak stress after 25 seconds which was regarded as the yield stress. It is possible to utilize the Brookfield Rotational viscometer equipped with the UL Adaptor to measure yield stress in the same way. Due to the narrow gap and the ratio of cup diameter to bob diameter of 1.098, the shear rate can be mathematically shown to be 0.61 s^{-1} at 0.5 revolutions per minute for the Model RVT viscometer. The manner of introducing the suspension to the cup, the settlement time, and other forms of treatment depend upon the interest of the investigator. However, once the sample is in the cup, the controlled shearing begins and the shear stress will reach a maximum value before dropping off. This is believed to be the moment when flow actually begins and is recorded as the yield stress. It is interesting to note that this is precisely the operating definition of 'apparent' yield stress given by JAMES *et al.*, (1987). In view of the great variability shown between yield stress and bed concentration for different muds, between different workers (McCAVE, 1984) and from different techniques, *e.g.*, direct measurements (stress relaxation, shear vane rotation) and indirect extrapolation methods, assuming various plastic flow models (NGUYEN and BOGER, 1983), it seems that closer discrimination without some standardization is unwarranted.

History of Use in Sedimentology

The Brookfield rotational viscometer has had a considerable history in the investigation of modern sediments. It has been used to characterize dense nearbottom suspensions from the coastal mud belts of Suriname (NEDCO, 1968; WELLS and COLEMAN, 1981), Brazil (FAAS, 1985), Belgium (VERREET *et al.*, 1986); from the Chao Phya estuary (NEDCO, 1965), the Rappahannock estuary of Chesapeake Bay (FAAS, 1981); and a variety of estuarine, marine, and freshwater muds (MIGNIOT, 1968). It offers the sedimentologist a way to examine and experiment with his material, *e.g.*, suspensions of fine-grained sediments, in ways which appear to emulate nature. This can be done with a simple, inexpensive instrument, which, when equipped with the appropriate adaptors, is capable of producing rheological data comparable to that derived from far more expensive and sophisticated instruments, between which there appears to be little agreement (JAMES *et al.*, 1987).

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