

Design Considerations for Modification for Greases

The viscometer described in the foregoing is satisfactory for measurement of viscosity up to about 1000 poise. This corresponds to a fall time $\tau = 1000/0.88$ seconds, or about 20 minutes. Longer times are impractical. It is of particular interest to examine higher viscosity conditions, especially the apparently sudden gel formation. The most convenient form of viscometer for this purpose is one in which a cylinder rotates coaxially with a slightly larger cylinder, the fluid being contained in the annular space between them. The most direct measurements of this type are obtained with continuous rotation but this involves determination of the torque, which is experimentally difficult in a high-pressure vessel, and is subject to errors. Reliable commercial grease viscometers are, however, available which depend upon the torsion in a wire. The inner cylinder is suspended from a long, thin wire, the upper end of which is attached to a torsion head. To make the measurement either the torsion head is rapidly rotated through 90 or 180 deg and the time for the cylinder to follow through an appropriately smaller angle is recorded, or the torsion head is rotated while the cylinder is held and the time is measured from the instant of releasing the cylinder. The latter method is more accurate for low-viscosity fluids, but is less easily adapted.

It is proposed that the former method should be used for the high-pressure viscometer. The torsion head can be mounted in the same way as the ball-release device shown in Fig. 2 and the cylinder can be suspended from a torsion wire extending through the length of the fall tube. Experiments with an unpressurized system of this sort have shown that the angular position of the cobalt ball embedded near the surface of a suitable cylinder can

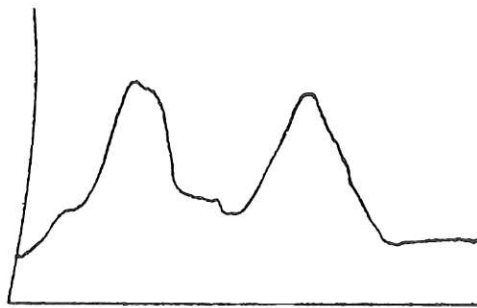


Fig. 11 The Geiger counter traces obtained as design data for a high-pressure grease viscometer, usable up to 10^4 poise

be detected by a collimated Geiger counter through the requisite $2\frac{1}{4}$ in. of steel as shown in Fig. 11. Two such Geiger counters could thus be mounted at a predetermined angular separation of say 75 deg in a lead block to detect the rotation of the cylinder. Better discrimination would be obtained by inserting a 0.5 mm dia cobalt wire of comparable radioactivity in a 2 cm longitudinal hole just below the surface of the rotating cylinder. The Geiger counters would then be inserted behind $\frac{1}{16}$ in. vertical collimating slots in the lead. A more elaborate possibility would be to mount a single counter on a trolley running along a concentric track and to arrange a servo drive to lock on to maximum signal. In this way the movement of the counter trolley would be synchronized with the rotation of the cylinder. The simple system would however give reliable results for all conditions of steady rotation. Viscosities up to 10^4 poise can be measured in this type of apparatus.

W. Webb²

The author has presented two novel features in this paper that seem promising. One of these is the determination of the density of the fluid being investigated by using two spheres of differing density and securing two sets of viscosity data essentially simultaneously. The check that these two sets of data yield gives assurance of internal consistency that can be comforting in high pressure work where endless trouble seems to arise. This method does place rather severe demands on the timing accuracy, for the calculation of the fluid density depends on the difference of two somewhat larger numbers. The second novel feature is the design of the Geiger counter method of measuring the passage times. While the author's electrical method of measuring the passage times would certainly give adequate accuracy for the determination of the fluid density it is not clear from the curve in Fig. 3 that the Geiger counter method would. It would be interesting to know just what precision the curves yield for the passage times.

As the author points out the logarithm of the viscosity versus the pressure yields nearly linear curves. In fact all the curves shown except one, in Fig. 5, are straight. One must be warned however that this is by no means general as shown by the curves for more extensive pressure ranges in the author's reference [20], Pressure Viscosity Report, American Society of Mechanical Engineering. The author of course does not suggest, directly, such a generalization.

The use of an absolute instrument presents many difficulties that the use of relative instruments does not present. In view of this it is not clear why the author chooses to attempt an absolute measurement when a relative instrument would supply the needed viscosity data for the study undertaken. Does the author have some reason to doubt the reliability or the validity of the relative instruments he describes in his survey of previous work?

W. O. Winer³

The writer would like to suggest that in the cases of elastohydrodynamic lubrication and metalworking that the effect of shear stress on viscosity should be considered as well as the effects of pressure, temperature, and time. This is particularly true when gelation begins to occur as a result of a combination of temperature and pressure. Much information along this line has been gained in connection with the determination of low temperature viscometric properties of engine oils at atmospheric pressure which indicates that the effect of shear stress (or shear rate) can be significant when gelation occurs. Unfortunately in a falling-object instrument such as that used by the author it is virtually impossible to detect these shear-stress effects.

It should be mentioned in connection with this paper that the silicone oil used (DC 704 a phenyl methyl siloxane) is specifically produced to be used as a vacuum system diffusion pump oil and not a lubricant. Hence it is not surprising that it is a poor boundary lubricant.

Also in connection with the silicone oil, I would like to raise the question of the accuracy of the data. This particular silicone oil has a kinematic viscosity at 25 deg C of 30 to 40 cs and a density of about 1.07 gm/cc resulting in an absolute viscosity of 32 to 43 cp at 25 deg C. Fig. 6 in the paper, which presents the data obtained on the silicone oil, indicates a viscosity of 100 cp when the data are extrapolated to atmospheric pressure. It would be of interest to know if the viscometer was calibrated with a viscosity standard and, if so, what the result was in comparison to the result from Stoke's "law" with the various corrections.

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In general, the writer is of the opinion that the terms "freezing" and "solidification pressure" are misleading in this field and that the term "gelation" is preferable, possibly, because it is more ambiguous.

W. J. Ewbank⁴

I recently had occasion to study the paper by Prof. G. Rowe on measurement of viscosity at 20 T/sq in. Since the derivation is based on Stoke's law, it assumes that the materials are Newtonian, and independent of the rate of shear. There appears to be considerable doubt that even hydrocarbon based materials are fully Newtonian at these high pressures.

Certainly, the lubricating greases discussed in Appendix 2 are highly non-Newtonian. I would therefore suggest that not two, but several Geiger counters be installed so as to obtain the viscosity as a function of shear rate, as well as of pressure and temperature. This apparatus could then also be used to determine whether or not lubricating oils are Newtonian at high pressure.

Author's Closure

In reply to Professor Webb, I consider that if an absolute instrument can be made and used without difficulty this is to be preferred to any equipment providing only relative results. Interpretation of the results and their eventual use in theoretical predictions is then simplified. Our proposed method is very simple and it is not limited to the high viscosities which were of interest in our experiments since a low-density ball, for example of a polymer plated with cobalt and irradiated to a high specific activity, could be used. Accurate control of pressure, temperature and fluid composition is equally important for all viscometers, whether relative or absolute.

We have no proper statistical evidence of the accuracy of the timing, but the general reproducibility of the data can be assessed from Figs. 4-9. High specific activity, low speed of descent and good collimation contribute to accuracy. Our meas-

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urements were made at three levels on the pen records, and also from a timer triggered at preset voltage levels. I agree that the inductance method is numerically more precise but this is outweighed by the necessity for calibration against some other instrument and the strong dependence of the accuracy on dimensional tolerances.

Although the results often produce a straight logarithmic plot, it should certainly not be assumed that all fluids will yield such a result. Incidentally, the curved line in Fig. 5 refers to Hyde's data. Fig. 6 also shows some curvature, and this may explain the comment by Professor Winer that linear extrapolation of Fig. 6 indicates 100 cp at atmospheric pressure, compared with the accepted value of 40. The data in Fig. 6 fall below the linear extrapolation, but I would not claim high accuracy in this low-viscosity range with the high-density ball. As he says, no one should be surprised that the diffusion pump oil showed poor lubrication. We chose it explicitly, as in earlier work, for its poor boundary lubrication properties.

I agree that the influence of shear strain rate is often important, as shown in reference [1] of the paper. It might be possible to introduce this parameter as part of the study with the concentric-cylinders modification mentioned in Appendix 2.

Professor Webb correctly points out that our method of measuring density by using two balls is less accurate than the viscosity measurements themselves. I think the technique is nevertheless justified since we require only a correction term, and moreover this involves $(\rho_1 - \rho_2)$. Since ρ_1 is accurately known and is much greater than ρ_2 , the accuracy of η is not directly dependent upon that of ρ_2 .

It is clear that any viscometer based on Stokes' Law will be in error when the fluid does not flow in a Newtonian manner, and it is of considerable interest to examine this feature at high pressures. Professor Ewbank has made a valuable suggestion that several counters might be used. I envisaged similar information becoming available from the servo locking system proposed in Appendix 2, but this has not been built. This would be of particular value in examining the gel formation more closely. While sharing Professor Winer's doubts about the term "solidification pressure," I would recommend deferring a decision on nomenclature until more experimental evidence of this type is available.