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THE

BRITISH SOCIETY
OF RHEOLOGY

BULLETIN

No. 55

THE BRITISH SOCIETY OF RHEOLOGY



New Members.

NAME AND ADDRESS.	INTERESTS.
P. A. T. Farrow, Esq. c/o Farol Research, North Bersted, Bognor Regis, Sussex.	Rotational and oscillatory viscometry.
Dr. J. R. Arthur, Fisons Ltd., Levington Research Station, Ipswich, Suffolk.	Rheology of damp inorganic aggregates.

News of Members.

Prof. Marcus Reiner of the Israel Institute of Technology has been awarded the highest honour which Israel gives to her citizens, namely, what is known as "an Israel Prize."

In a letter to the Editor of the *Jerusalem Post*, Prof. Marcus Reiner pointed out that although rheology as a branch of physics is relatively new yet its beginnings go back to the prophetess Deborah who correctly stated that "the mountains flowed before the Lord" an observation which the Greek philosopher Heraclitos generalized to "Everything flows."

Dr. C. A. Seyler has retired from the post of Head of the Dept. of Coal Petrology at the British Coal Utilisation Research Association. Dr. Seyler, who is in his ninety-second year, joined the Society in 1944. He is in good health and is now living at 4, The Chain, Abergavenny, Monmouthshire.

Mr. N. Wookey, Hon. Secretary of the Society, has recently been appointed a director of The Dunmow Engineering Company Limited. He also retains his present appointment at Scribbens-Kemp (Research and Development) Limited.

Death.

The Committee regrets to record the death of Prof. R. M. Davis, Prof. of Physics in the University College of Wales, Aberystwyth. Prof. Davis joined the Society in 1949.

Future Meeting.

The British Society of Rheology wishes to give preliminary notice of a meeting to be held in the Department of Glass Technology of the University of Sheffield from 15th to 17th April, 1959, on "The Rheology of the Glassy State."

The meeting will discuss the mechanical and optical properties of inorganic and organic glasses and of high polymers in the glassy state. Intending contributors are invited to submit a title and detailed abstract (200-400 words) before 15th September, 1958, to Dr. D. W. Saunders, British Rayon Research Association, Heald Green Laboratories, Wythenshawe, Manchester 22, England. Complete manuscripts will be required by mid-January, 1959.

News of Societies.

Members of the Society are invited to attend a meeting of the London Section of the Oil and Colour Chemists' Association when Mr. C. C. Mell will present a paper on "The Rheological Behaviour of Paint Systems at Low Shearing Rates." The meeting will be held at the Royal Society of Tropical Medicine, Manson House, 26 Portland Place, London, W.1, at 7 p.m. October 22nd, 1958. Tea will be available in the library from 6.15 to 6.45 p.m.

The 1958 Christmas Symposium of the Industrial and Engineering Chemical Division of the American Chemical Society is to be on the general subject of the fluid mechanics of non-Newtonian materials and is to be held on 29th and 30th December, 1958. Research papers are invited and completed papers should be submitted by about 1st October, 1958, and abstracts (200 words) as early as possible, to R. E. Colwell, Monsanto Chemical Co., Plastics Division, Springfield 2, Massachusetts, U.S.A.

The 1958 Annual Meeting of the U.S. Society of Rheology has been arranged for 5th to 7th November at the Franklin Institute, Philadelphia. It is planned to group papers for the meeting around several symposia which include Resonance and Relaxation Phenomena, Flaw Mechanisms at high shear rates, Use of Models in rheology, Mathematical aspects, computers, etc.

A new rheology journal, "Rheologica Acta" has just been published. Founded under F. H. Miller, Editor of Kolloid-Zeitschrift and president of the third International Congress of Rheology to be held at Bad Oeynhausen (Germany), the journal will form independent supplements to Kolloid-Zeitschrift and be published by Dr. Dietrich Steinkopff in Darmstadt, and will serve as the medium of publication for the Proceedings of the Third International Rheology Congress.

Summaries of papers read at the Symposium on the accurate measurement of the viscosity of liquids, held jointly by the Institute of Petroleum and the British Society of Rheology, 6th June, 1958, at the Institute of Petroleum, 61 New Cavendish St., London, W.1.

The Determination of Viscosity by the Oscillating Vessel Method.

By R. ROSCOE, King's College, Newcastle-upon-Tyne.

Further development of accurate absolute methods of viscosity measurement is desirable, particularly for the determination of the viscosity of liquids suitable as standards in viscometry. The principal difficulty in the capillary tube method lies in the elimination of the end correction, and this necessitates the use of two tubes of different length with identical ends. It appears that the slight inconsistencies in the very careful measurements of Swindells, Coe and Godfrey (who found the viscosity of water at 20°C to be 1.0019 ± 0.0003 cP) arise from small differences in the ends of paired tubes.

The oscillating vessel method, advocated by Andrade and Chiong, may therefore prove to be better for accurate work. Here the liquid is contained in an axially symmetrical vessel held by a torsional suspension and set in rotation about a vertical axis. The viscosity can be obtained (by a rather complicated calculation) from observations on the logarithmic decrement and time period of the system. A new and accurate method of calculation for use with spherical, nearly spherical and cylindrical vessels is discussed briefly, as is the effect of external air resistance.

Theoretical considerations show that the amplitude of the oscillations must be small for accurate work. The method has been used in some new measurements on the viscosity of water made in collaboration with Mr. W. Bainbridge which will be published in detail elsewhere. A spherical vessel was used with a graduated capillary tube as its stem, so that the water acted as its own thermometer. The result obtained was 1.0025 ± 0.0005 cP. An analysis of the sources of error in this result suggests that, with fairly simple improvements in technique, the accuracy of the method could be made substantially greater than that attained in capillary tube measurements. Among suggested improvements are the use of a cylindrical vessel and the determination of the logarithmic decrement from measurements of angular velocity rather than amplitude of oscillation.

Measurement of Viscosity by an Electronic Counting Technique.

By M. T. BROWNE (Imperial College and Queen Elizabeth College).

The viscosity is derived from measurements of the damping of a vibrating system, a beryllium-copper rod, 12" long by $\frac{3}{8}$ " diameter held centrally by four screws, immersed in the medium, the measurements being made by means of an electronic counting technique.

For small values the logarithmic decrement is $\delta \simeq \Delta W/2W$ where ΔW

is the energy absorbed in each cycle of vibration and W is the total energy of vibration.

To calculate the damping arising from the viscous resistance of the fluid medium it is necessary to evaluate the "surface loading" which is completely specified by the driving point impedance of the medium, Z_0 = amplitude of shear stress/partial velocity, which may, in general, be written $Z_0 = R_0 + iX_0$. The real component R_0 results from a truly resistive force in phase with the particle velocity while X_0 is the out of phase component. Thus, for a rod in torsional free-free vibration, held vertically, and immersed in a fluid medium to a depth y , the resultant logarithmic decrement is

$$\delta_T^y = \frac{2nR_0}{wl\rho_s} \left[1 + \frac{2}{r} \left(y + \frac{l}{2n} \sin \frac{2ny}{l} \right) \right] \quad (1)$$

where w is the angular frequency, l the length and r the radius of the rod and ρ_s the density of the material.

The relation between R_0 and viscosity, η , for plane shear wave propagation in an infinite viscous medium of density ρ , is $R_0 = (w\rho\eta/2)^{1/2}$.

If the liquid is in the form of a thin film some energy may be reflected back from the boundary. If the surface of the film is free

$$R_0 = \left(\frac{w\rho\eta}{2} \right)^{1/2} \frac{1}{2} \left[\frac{\sinh 2\theta - \sin 2\theta}{\cos^2 \theta + \sinh^2 \theta} \right]$$

but if the surface is bounded by a solid

$$R_0 = \left(\frac{w\rho\eta}{2} \right)^{1/2} 2 \left[\frac{\cos^2 \theta + \sinh^2 \theta}{\sinh 2\theta - \sin 2\theta} \right] \quad (2)$$

where $\theta = (w\rho/2\eta)^{1/2}t$ and t is the film thickness.

The beryllium-copper rod is driven in its fundamental torsional mode by the interaction of an alternating current in a coil wound in grooves in the surface of the rod and a transverse magnetic field. A similar coil wound orthogonally to the first acts as a pick-up coil and feeds a decaying voltage to the electronic apparatus when the "drive" is switched off. The electronic apparatus is actuated and counts the number of cycles of vibration (N) occurring while the amplitude decreases from one value to half this value; thus the log. dec. $\delta = \frac{\log_e 2}{N}$

The experiments with this apparatus have been used to confirm the form of equation (1) and (2) and to calculate viscosity; with water the results agreed with the accepted static viscosity to within 1%.

With a higher viscosity liquid a drop was located on a plane end of the rod and the results agreed to within 3% of the standard values. The range of frequency that could be covered by this apparatus, determined principally by the natural frequency of the chosen vibrating systems, is of the order 1 to 100 K/C.

The apparatus is particularly adapted to measure small changes of viscosity if these can be induced without altering the conditions of the vibrating system.

Viscosity Measurements at High Rates of Shear

By ROBERT SCHNURMANN (Esso Research Limited)

Industry has become "shear" conscious during the last two decades mainly in connection with the requirements of the armed services and the automotive industry. At the rates of shear at which viscosities are usually measured the viscosity of liquids does not show variations, but when the rate of shear reaches large values the coefficient of viscosity is no longer a constant; appreciable flow orientation of the molecules takes place with the immediate practical result of a temporary viscosity reduction while the shearing stress persists, accompanied by a decrease of the viscosity-temperature coefficient. If sufficiently large long chain molecules are in the liquid high shearing stresses will bring about a permanent viscosity loss. Under laminar flow conditions it has been necessary to attain rates of shear of more than $1.6 \times 10^6 \text{ sec}^{-1}$ to break down molecules of molecular weights of 25,000, whilst larger molecules of molecular weights of 100,000 can already be broken down at mean rates of shear of the order of 10^5 sec^{-1} .

It is important to be able to measure viscosities at these high rates of shear which occur in practice in hydraulic mechanisms and in closely fitting bearings. At these high rates of shear of the order of 10^5 sec^{-1} , experimental conditions must be established so that the sheared liquid suffers no heating, all the mechanical energy being used to shear the liquid. This is an important point because high shearing stresses can be produced by a variety of means but most of these involve appreciable temperature rise. The complication of heating by friction forces is practically eliminated when a liquid is forced slowly and in individual drops through a narrow streamlined constriction, which behaves effectively like a short capillary of a length-to-diameter ratio of about 2.5. By varying the pressure difference across this aperture between about 5 mm. Hg and 760 mm. Hg. at a given temperature of the liquid in the reservoir, or by varying the temperature, the rate of shear can be altered within wide limits. The kinetic energy correction for this "jet viscometer" can be determined experimentally, and is smaller by a factor of about 2 than for long capillary viscometers which usually have a length-to-diameter ratio of 100.

The viscosity of any liquid containing elongated molecules—even quite short—can be made to show a temporary viscosity reduction. Castor oil, for example, appears to have a constant viscosity coefficient for rates of shear up to $5,000 \text{ sec}^{-1}$, yet at a rate of shear of $250,000 \text{ sec}^{-1}$ its viscosity is reduced by about 25%.

The apparent viscosity has, over a wide range of rates of shear, a falling characteristic with a point of inflexion. The curve bends upward when an appreciable proportion of the pressure-volume energy is converted into kinetic energy and when turbulent flow takes place. Thus, to assess quantitatively the temporary viscosity reduction for any particular value of the rate of shear, and to determine the critical Reynolds' number, the kinetic energy correction must be applied to the experimental results. It has been shown that the critical Reynolds'

number depends upon the length of the largest molecules in the liquid, their concentration and the rate of shear.

The viscosity of a liquid which has suffered a permanent viscosity loss through severe shearing is more sensitive to temperature change than that of the liquid at low rates of shear. On the other hand, when a liquid suffers a temporary viscosity reduction its viscosity-temperature coefficient is smaller while a shearing stress is applied than when the stress has been removed.

A Short Report on the Standard Methods of Measuring Viscosity in c.g.s. Units.

By W. JENNINGS (National Physical Laboratory) and E. W. J. MARDLES
(Chairman of Viscosity Panel, Institute of Petroleum).

The revised standards of measuring the viscosity of liquids in c.g.s. units incorporate the experience and the results of co-operative experimental work obtained in this and other countries during the post war years.

The opinion expressed by Dr. Guy Barr, at the first World Petroleum Congress 1933, that the international standardization of viscosities should be made with viscometers of known characteristics, as these are much less likely to change than standard viscosity oils, has been confirmed by the findings of the viscosity committees. The recommendations of the joint meeting of the Institute of Petroleum and the British Society of Rheology, June 1945 (I.P. Journal 31, No. 26, August, 1945) have been implemented and the practical findings used in the compilation of the revised standards. These specify acceptable types of instruments, course of procedure and a "step-up" method of calibration, rigid cleaning and filtering processes, a high precision in temperature control and timing, methods of calculating the coefficient of viscosity from flow times while information is included relating to the effect of air buoyancy, change in gravity and of other factors.

An account is given of the results obtained at the National Physical Laboratory when putting into practice the methods of glass capillary viscometer calibrations and viscosity measurement given in standards B.S. 188: 1957 and I.P. 71/58. The establishment of a series of reference viscometers on the basis of the agreed viscosity value of water is described. The accuracy of the method is assessed by cross checks with other laboratories. A summary of results obtained during routine calibrations of viscometers for industry is included and a simplified method of calculation for this type of work described.

Measurement of the Viscosity of Polymers at Extremely Low Concentrations.

By P. P. RUTHERFORD (University College of North Staffordshire).

Viscosity measurements for several polystyrenes in a series of different solvents at 15° and 25°C. using a U-tube capillary viscometer, gave anomalous $\eta sp/c$ and $\ln \eta r/c$ values at the highest dilutions. For poly-

styrenes of molecular weight less than 40,000, upswings in the graphs were observed when the above values were plotted against the concentration over the range 0.2 to 0.4 g of polymer per 100 ml of benzene at 25°. The concentration at which these upswings occurred depends on (a) the intrinsic viscosity or molecular weight, (b) the temperature and (c) the kind of solvent used.

Control methods and the procedure of precise measurement with results for specially prepared polymers are given; the repeatability was of the order 0.1 %.

The flow times for the dilute solutions left in contact with powdered glass for several months were found to be almost unaltered indicating that adsorption effects are negligible. The anomalous behaviour of polymers at low concentration and the dependence of this concentration on the intrinsic viscosity of the polymer are real effects, but before any conclusion can be drawn it is necessary to continue the work not only by viscosity measurements on a series of fractionated polystyrenes of low molecular weight but by the measurement of other properties, such as, for example, light scattering and density in the low concentration range.

Course of ten Lectures on Rheological Techniques.

The course is suitable for Physicists and Chemists and will be held at the Battersea College of Technology, London, S.W. 11, on Tuesdays, 6.30 to 8.30 p.m., commencing 7th October, 1958, by R. W. Whorlow, B.Sc., A.Inst.P. Fee for the course—£1-0-0.

The emphasis throughout the course will be on the theory of experimental methods leading to absolute measurements of stress and strain. Examples of instruments and results will be drawn from a wide range of industries.