

BULLETIN OF THE
BRITISH RHEOLOGISTS' CLUB



Address for communications: c/o The Institute of Physics,
at The University, Reading, Berks.

NO. 1

JANUARY 1941

Issued (gratis) to members of the Club only.

CLUB NOTES.

Inaugural Meeting.

A very successful inaugural meeting was held at Reading on the 16th November, 1940, an account of which, reprinted in "Nature" is attached. Mr. Pryce Jones' opening paper is being published very shortly in the Journal of Scientific Instruments.

Membership.

At the time of writing the club has 82 members which include engineers, physicists, chemists, biochemists, bacteriologists, etc. The materials in which members have expressed interest include:- Adhesives, Blood, Cellulose derivatives, Ceramics, & Clays, Dairy products, Emulsions, Flour, Food-stuffs in general, Glass, Ink, Metals, Muscle, Oils and greases, Paints, Enamel etc. Pastes, Photographic materials, Plastics and resins, Rubber, Soils etc, Starch, Tars, Bitumens, and Road materials.

Co-operation between members.

Members are reminded that the club officers will always be happy to assist members to communicate with others working in their special fields.

The next Meeting.

By kind invitation of the Director, arrangements are being made to hold the next meeting of the Club at Latra House, Robin Hood Court, Shoe Lane, London, E.C.4. It is proposed that the meeting shall start at about 11.30 a.m., the subject for discussion being "Rotation Viscometers and Thixotrometers" (Provisional date, Saturday, February 22nd) Details of this meeting will be circulated to members in due course.

The Bulletin.

Future issues of this bulletin will appear at irregular intervals. The Committee wishes to thank members who have so willingly co-operated by providing abstracts and articles. Further contributions and suggestions are invited.

RHEOLOGY IN INDUSTRY

I. Rheology in the Printing Ink Industry, by V.G.W. Harrison, B.Sc., Ph.D., A.Inst.P., Senior Physicist, Printing and Allied Trades' Research Association.

Printing inks consist essentially of a pigment ground into an oily vehicle. The purpose of the vehicle is twofold: first, it enables the pigment to be distributed easily and evenly over the printing surfaces, and secondly, it acts as a binding medium for attaching the pigment to the paper or material being printed. Vehicles are of two main kinds: (1) mineral oils, and (2) drying oils, such as linseed and tung oils. Inks made on a mineral oil basis are used mostly for printing newspapers and magazines in which a highly absorbent paper is used. "Drying" of such inks takes place by the absorption of some of the vehicle by the paper, leaving a fairly hard and apparently dry mixture of pigment and vehicle on the surface.

Inks/

Inks of the second class dry by oxidation of the oil to form a hard, rub-proof film in which the pigment is embedded; such inks are used for better class work and for printing on non-absorbent surfaces.

The physical properties of printing inks are important. In the printing press, ink is placed in a duct and is fed by a rotating roller through a narrow adjustable gap on to the distributing rollers. These rollers break up the ink thoroughly and spread it on to the printing block. Finally, the paper is pressed into contact with the block and most of the ink transferred from block to paper. Trouble may arise at each of these stages if the rheological properties of the ink are unsuitable.

In the first place, ink sometimes refuses to feed properly through the narrow gap of the ink duct. Instead, it rolls round and round on top of the duct and very little is transferred to the rollers. The cause of this behaviour is not clear, but it seems probable that the ink is behaving as a plastic with a "yield value" so high that the shearing received in the duct is insufficient to liquefy it; also the degree of wetting of the duct roller by the ink seems to be important.

The purpose of the distributing rollers is to break down the thixotropy of the ink and to smooth out any irregularities in the feed of ink from the duct. The ink is usually passed from one to another of a chain of many rotating rollers, some of which are provided with a reciprocating motion along their axis. With high speed presses a trouble which frequently arises is spraying of ink from the rollers, some inks being much worse in this respect than others. Ink spray is of two kinds, (1) fairly large drops, which seem to be thrown off the rollers by centrifugal force, but which are not found at any great distance from the machine, and (2) a fine mist, which has a strong tendency to persist and which can be carried for distances of several yards. This mist deposits on sheets of paper stacked in the room, causing an objectionable discolouration. The reasons for this misting are obscure and are the subject of research. It seems probable, however, that properties such as viscosity, surface tension and fibrosity are involved.

For satisfactory prints, it is essential that the inked impression left on the paper should follow the outline of the type or block as closely as possible. An ink of too low viscosity tends to spread before drying is complete, causing blurring and distortion of tone values in halftone work. Also, when the block is mounted vertically, a low viscosity ink tends to run down the block before the impression is made, so that even inking is impossible. On the other hand, if the ink is of too high viscosity, large forces are developed in high speed presses at the moment when the paper is separated from the block, and these forces may be sufficient to tear off the surface layers of the paper. The pieces so torn off leave objectionable white specks in the print, and the detached paper fibers get covered with ink and fill up the spaces between the halftone dots of the block, giving dirty highlights.

It is thus obvious that, for the best results, the rheological properties of inks need study and control in the works; also, once the best inks for a given purpose are found, these properties should not be altered by the printer by the addition of oils, varnishes, etc. without good reason. At present, the control of the rheological properties of inks is still largely effected by the subjective estimation of such qualities as "body", "length" and "tack". These are not simple physical properties, but some combination of them which may or may not have any real bearing on the behaviour of the ink on the machine. One of the first problems of a rheologist who is required to place the grading of inks on a more scientific basis is to analyse these subjective judgements as far as possible. Thus "body" appears to involve mainly a study of anomalous viscosity, "length" denotes the capacity of an ink

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for being drawn out into long, fairly stable threads, and is thus connected with fibrosity, while "tack" is a vague term, but seems to be used mainly to denote the degree of stickiness felt when a film of ink is broken between forefinger and thumb. He must then decide whether these properties are important from the point of view of the printing process, and if so, devise methods for measuring them. Finally, and not least important, the results of the measurements must be interpreted in terms of the printing and working qualities of the ink.

The purpose of rheology in industry is not necessarily to replace the subjective judgments of the practical man, but to supplement them. Without instrumental means of measurement, errors are always liable to be made when the expert has his "off days" or is away from the works. This is now being increasingly realised and the position of rheology in the ink industry thus seems assured for some time to come.

RHEOLOGY ABSTRACTS

Note: The Club assumes no responsibility for the opinions expressed by abstractors; these are given in square brackets.

1. Pressure and Temperature Effects on the Viscosity of Liquids. D. Frisch, H. Eyring, and J.F. Kincaid. J. Appl. Phys, 11, pp. 75 - 80, 1940. - The authors regard viscous flow in liquids as due to the rolling of pairs of adjacent molecules over one another. For this to occur the pair must be endowed (by statistical fluctuations) with enough energy (1) to stretch or rupture bonds with their neighbours, and (2) in the case of high pressures, to force back their neighbours to provide enough room for rolling. (1) can be expressed in terms of the latent heat of vaporisation, (2) in terms of the pressure and molecular volume. The expression thus obtained for the viscosity as a function of pressure and temperature, contains two adjustable constants and agrees tolerably well with experiments on Hg, H₂O, C₆H₆, C₅H₁₂ (n- and iso-) and C₄H₁₀O. The authors admit that the treatment is so far little more than a reconnaissance of the problem. P.W.

2. Computation of some Physical Properties of Lubricating Oils at High Pressures: I. Density. R.B. Dow and C.E. Fink. J. Appl. Phys, 11, pp. 353 - 357, 1940. - The authors find that a wide range of lubricating oils (mineral, animal, vegetable, and fish oils) have roughly the same compressibilities. For $t = 25^{\circ}\text{C}.$, $40^{\circ}\text{C}.$, and $75^{\circ}\text{C}.$, the density $\rho_{t,p}$ at pressure p (in megadynes/sq. cm.) is related to $\rho_{t,0}$ thus: $\rho_{t,p} = \rho_{t,0} (1 + ap - bp^2)$ for p up to 3,000, where a and b vary with the temperature. For an average oil, a rises from 6.2 to 6.7×10^{-5} and b drops from 1.3 to 1.0×10^{-8} as t rises from 25°C to 75°C . For the various oils studied, the extreme a -values are in the ratio 7 : 9 (range of b not specified). P.W.

3. Pendulum Analysis in the Scale Industry. G.R. Carley. J. Appl. Phys, 11, pp. 314 - 324, 1940. - This paper contains the mathematical theory of the design of those shop-counter scales which indicate by pointer but do not contain springs (letter-balance type). It will be of interest to designers of rheometers in which the specimen is to be subjected to stresses varying with the strain in a pre-arranged way. P.W.

4. A Theory of Large Elastic Deformation. M. Mooney. J. Appl. Phys., 11, pp. 582 - 592, 1940. - The author deduces expressions for the strain-energy function of a substance, such as an idealised rubber, which had the following properties:- (1) homogeneity and freedom from hysteresis, (2) complete isotropy when undeformed, (3) when stretched, isotropy in the plane normal to stretching, and (4) constancy of volume.

For small deformations, the expressions involve two constants of the material, one being the rigidity, the other being a measure of the difference between the response to stretching and the response to squeezing. For large deformations the theory offers an infinite series of constants but the author's/

author's experimental data on gum stock up to a seven-fold stretching are accurately represented by the use of four constants only. The theory also fits Hencky's experimental results well (H. Hencky, J. Rheology, 2, p. 169, 1931, or Rub. Chem. Tech. 6, p. 217, 1933. P.W.

5. Flow Characteristics of Mud (control of drilling mud in the field). H.C.H. Darley. J. Inst. Petroleum, 26, p. 457, 1940. - This paper formulates no new theory but aims at establishing some system of classifying muds by their viscosity behaviour. An outline is given of the work of P.H. Jones and E.C. Babson (Oil Weekly 2/12/35) on the essential flow characteristics of mud expressed in yield point, dynes/cm.² and immobility in centipoises.

Jones and Babson found that if a thixotropic mud is sheared at a given speed it will gradually assume a deflection (MacMichael type viscometer) typical of that speed irrespective of its previous state of shear, the value being attained when equilibrium is established (10 to 30 minutes) between the gelling and disrupting forces. Darley recommends this viscosity method of test and states that the action of gel forming colloids is the basic factor in mud behaviour; he uses the ratio (colloidal index) of per cent solids in the equivalent standard clay base to that in the test clay base as an indication of the colloidal properties and of thixotropy.

The method of analysis of the viscosity data is empirical and the author's nomenclature needs revision. E.W.J.M.

6. The Permanence of the Physical Properties of Plastics. J. Delmonte. Engineering, 149, pp. 447-449, & pp. 456-457, 1940. - This article gives data on the physical properties of several plastics and a description of the apparatus used by the author for their determination. A definition of yield value is offered on the so-called 'elastic' and 'plastic' deformations and the 'elastic' and 'plastic' recoveries shown by a test piece which is first stressed and subsequently released. The effect of exposing the plastic to various service conditions is discussed; the changes so produced in the physical properties also receive attention.

The test apparatus consists of a clamp for holding a strip of the test material in a simple cantilever fashion, the test strip being loaded at its free end. W.G.W.

7. The Measurement of the Rheological Properties of some Industrial Materials. G.W. Scott Blair, J. Sci. Instr. 17, p. 169, 1940. - In order to classify materials in terms of their principal rheological properties, the author proposes that numbers from 1 to 5 be used to represent the intensity of eight principal properties, the resulting eight numbers to constitute a "rheological" formula. The eight properties are:-

I. Viscosity, II. Elastic (shear) modulus, III. Elastic after-effect and hysteresis, IV. Structural viscosity (fall in viscosity with rising stress), V. Sharpness of yield-value, VI. Permanent or temporary (thixotropic) break-down under shear, VII. Increase in consistency with straining: i.e. work-hardening or dilatancy, VIII. Tensile strength.

Although it is admitted that there are other important properties to be considered, it is suggested that, with these eight numbers, some useful ideas can be obtained to help in the choice of methods suitable for testing new materials. A table is given showing the distribution of rheological formulae among 24 different methods of testing materials as described in the literature, though it is pointed out that the survey of published data is far from complete and suggested that a much more useful table could be prepared with the cooperation of a group of rheologists. G.W.S.B.

8. An/

8. An Improved Rotary Viscometer. A.H. Nissan, L.V.W. Clark, and A.W. Nash. J. Sci. Instr., 17, pp. 33-38, 1940. - A Couette type rotary viscometer has been developed in which the chief sources of error in the type of apparatus namely end effects, eccentricity of cylinders relative to each other, variation of speed and variation of temperature have either been eliminated or reduced to a minimum so that an accuracy of 1% in the range of viscosities above 10 poises is claimed.

The paper illustrates these points, describes the apparatus and its method of eliminating end effects by means of a sharp edged weir on the rotating cylinder and a differential method of measuring the height of immersion of the inner cylinder.

Although an accuracy of 1 per cent in the range of viscosities above 10 poises is claimed, no mention is made of the upper limit to the range and this result has apparently been obtained from experiments on one class of fluids only, namely oils.

H.C.T.

9. A Coni-Cylindrical Viscometer for Measuring the Visco-Elastic Characteristics of Highly Viscous Liquids. A.R. Lee and J.B. Warren. J. Sci. Instr., 17, pp. 63-67, 1940. - A description is given of an absolute viscometer of the rotating cylinder type which has been constructed for the purpose of studying the flow characteristics of bituminous road binders. The instrument has been designed so as to reduce the sources of error common to the type of viscometer and accurate readings of viscosity are claimed over a range of 10^3 to 10^8 poises together with a value for the elastic recovery of the material under known conditions of shear, stress and temperature.

H.C.T.

10. Measurement of Paint Consistency. Oil and Colour Trades J., 98, pp. 578-582, 1940. (A Report by a sub-committee of the American Society for Testing Materials.) - In 1938 a survey by a committee of the A.S.T.M. indicated that, in the U.S.A., the Ford Cup No. 4, Gardner mobilometer and Stormer viscometer were the most commonly used instruments for the measurement of paint consistency. The committee, investigating the possibility of formulating an A.S.T.M. method for measuring the consistency of gloss and enamel type paints, distributed to various co-operating laboratories samples of five such paints, the consistencies of which were measured using A.S.T.M. Cup No. 10 and the three instruments already mentioned. Comparative tables show that the best agreement between laboratories was obtained using the Stormer viscometer. Accordingly the committee have issued a tentative specification for the measurement, by means of this instrument, of the consistency of "enamel type paints showing little or no false-body". They define "consistency" in terms of the shearing stress (wt. in grms.) required to produce a specified rate of shear (100 revs. of rotor in 30 secs.).

The use of the term "consistency" is to be deprecated, the quantity defined being, of course, a measure of the apparent viscosity at a certain (albeit specified) shear rate. In view of present rheological knowledge and technique available, the specification seems unduly empirical.

J.E.A.

11. Measuring Flow Temperatures of Thermoplastic Moulding Materials. (A proposed A.S.T.M. Tentative Method of Test.) British Plastics, 12, pp. 184-185, 1940. - This method of test determines the temperature at which a thermoplastic material attains a specified degree of flow when subjected to a prescribed pressure in an extrusion mould for a definite time. (A Rossi-Peakes flow-tester as described in U.S. Patent 2,066,016 is specified for the test.) Measurements of the flow are made at three or more temperatures and the temperature for the specified flow is obtained by graphic interpolation.

Although this tentative standard is welcome as a pioneering effort to characterise thermoplastic moulding materials it has certain/

certain drawbacks. The temperature of the test sample is not allowed to come into equilibrium with that of its surroundings - i.e. the test temperature before the flow takes place, and therefore the property measured is not one of flow only - it must include in some way the heat conductivity and perhaps the specific heat of the test material. Moreover the test pressure is constant; no attempt is made to measure the flow in absolute units of viscosity or to study the effect of varying the applied stress - which effect, quite a definite one, has been observed by the abstractor in certain thermoplastic materials. W.G.W.

12. The Subjective Judgment of the Elastic and Plastic Properties of Soft Bodies. G.W. Scott Blair and F.M.V. Coppen. Brit. J. Psychol. (Gen. Sec.) 31, p. 61, 1940. - Experiments are described on the self-consistency and learning ability of various types of person in reproducing judgments of the comparative 'firmness' of materials differing in both elastic and plastic properties.

Technologists used to judging similar materials show little superiority in earlier tests and are somewhat inferior in later tests. Routine analysts, however, show a marked superiority. These results are believed to depend upon mental attitude.

A marked correlation was found between the force and speed of handling and the relative rank positions given to 'springy' and 'dead' materials. It is also shewn that a true fluid and a true solid can be compared directly for 'firmness' and that an eight-fold difference in time of handling causes a reversal of 'firmness' judgment over wide ranges of viscosity and compression modulus.

The mean subjective order for the eight materials used agreed closely with the objective measurements of total deformation produced under standardised loading conditions. F.M.V.C.

13. Clay-water Relationships. H.H. Macey. Proc. Phys. Soc. 52, pp. 625-655, 1940. - It is shown that if the plastic mixture of clay and water be subjected to a steady pressure between porous pistons, the applied pressure P is related to the equilibrium moisture-content M by the expression $P = \alpha e^{-\beta M}$, and the aqueous conductivity C obeys a similar relation $C = \theta e^{\phi M}$. The validity of the assumption that the water movement during drying is associated with the pressure P , and that of the extrapolation of the empirical formulae for P and C to moisture-contents below those possible experimentally, is demonstrated by a comparison of experimental and calculated moisture-content distributions in clay bars drying from one end only.

The variation in C cannot be explained if the viscosity of the water in the mixture is the same as that in bulk, but the experimental data on a wide range of clays are in agreement with the supposition of an anomalous viscosity, very large at the solid-liquid interface, and decreasing exponentially with distance from this interface. This is attributed to an intensity of crystal structure in the water which decreases from the interface in a similar manner.

✓ A very thorough study of a large number of clays. L.R.G.T.

14. The Viscosity of Suspensions in Non-aqueous Liquids. E.W.J. Mardles. Trans. Faraday Soc. 36, pp. 1007-1017, 1940. - Viscosity measurements have been made, avoiding low rates of shear, of suspensions of kaolin, graphite, and other solids, over a wide range of concentrations, in several organic liquids. Viscosities of suspensions, higher than the theoretical, appear to be due mainly to the disturbance of laminar flow by the precessional movement and the mutual interference of the dispersed particles, alone or in aggregates. Differences in viscosity behaviour of suspensions in viscous and thin liquids are ascribed to the more sluggish rotational movement of the particles in the former case. L.R.G.T.

15. A Simple and Accurate Viscometric Form of Rennet Test. C.W. King and E.M. Melville. J. Dairy Res. 10, p. 340, 1939; 11, p. 84, 1940.- The authors discuss the work of C. Christen & E. Virasoro (Lait. 12, p. 923, 1932, and 15, p. 354, 1935), who followed the coagulation of milk by rennet in a viscometer of the torsion type, and they conclude that an oscillating disc type of viscometer designed by them is better suited to the problem than the apparatus used by the earlier authors. At the point of coagulation the viscosity rises very steeply and the exact time taken for coagulation of a milk under standard conditions, which is an important criterion of its quality for cheese-making, is thus easily determined. The second paper describes a modification of the apparatus as described in the first. G.W.S.B.

16. Further Observations on Basic Viscosity of Ice Cream Mixes and a Simplified Procedure to obtain them. A. Penczek and A.C. Dahlberg. J. Dairy Sci. 23, p. 691, 1940. - A basic viscosity is obtained in a viscometer of the Ostwald type after the false-body of the mix has been thoroughly broken down. Appreciable re-setting occurs if the mix is left to stand for as long as five minutes. The comparative merits of several methods for breaking down false body are discussed and it is concluded that a hand emulsifier is most effective. The nature of the thixotropic structure in cream is discussed. G.W.S.B.

17. An Objective Measure of the Consistency of Cheese Curd at the Pitching Point. G.W. Scott Blair and F.M.V. Coppen. J. Dairy Res. 11, p. 187, 1940. - In the manufacture of hard cheese, milk is coagulated by rennet into a junket which is later cut with knives into small pieces which are stirred in the whey which they exude by syneresis while the temperature is slowly raised. When the curd reaches a certain consistency the stirring is stopped and the curd settles (i.e. is "pitched"). This consistency, which is vital to the quality of the cheese, has hitherto been judged by the cheese-maker by handling the curd. The authors describe a method for measuring the superficial density of a cylinder of packed curd cast in a standard way, this property depending on the amount of whey which has been able to drain from the curd. The more rigid the curd particles, the more whey can escape and be replaced by air. The test, which takes less than 1 min. to perform, gives data which appear to correlate well with cheese-makers' judgments. G.W.S.B.

18. (i) Experiments on the Elasticity of Emmental Cheese Curd. G. Koestler. Ann. Agric. Suisse. 41, p. 127, 1940.

(ii) On the So-called Collapse ("Einfallen" of Emmental Cheese. Ibid. p. 195.

(iii) On the Question of Emmental Cheese Curd. Ibid. p. 587.

(iv) The Swelling Capacity of Emmental Cheese Curd, its Fundamental Nature and Meaning with reference to the Qualitative Judgments of Different Curds. Ibid. p. 605. (All in German with French Summaries.) - (i) The author compresses blocks of curd 6.5 x 6.5 x 25 mm. under loads of 50, 100, and 200 g. for a period of 120 sec. followed by a recovery lasting 120 sec. and from the data obtained, constructs deformation-time curves taking points every 15 secs.

He studies the effect of variations in age, salt content, moisture etc. on the rheological properties. Variations in elastic properties in different parts of the same cheese are not paralleled by measurable chemical differences.

(ii) The collapse which takes place when certain Emmental cheese left to ripen is not found to be correlated with the rheological properties measured as in paper (i). Ripening changes are discussed in terms of bound water.

(iii) Two rheological properties, hardness-softness and granular and smooth consistency are discussed as fundamental to Emmental cheese, four extremes being recognised - hard-granular,

hard-smooth/

hard-smooth, soft-granular, and soft-smooth. The former property is measured by the methods described in paper (i) and the latter by some type of penetrometer.

(iv) The amount of swelling of cheese in water and standard salt solutions after equilibrium has been reached is claimed to be correlated with cheese quality as assessed by experts.

Throughout this work it appears that the author has made a slip in the formula for determining per cent elastic recovery after release of load. This (described as "Elasticity" is given as $100(l_1 - l_2)/l_1$ where l_1 is total and l_2 recovered deformation. The correct expression is surely $100l_2/l_1$. Interrupted communications with Switzerland have prevented the reviewer from receiving an explanation from the author. In paper (iv) the expressions "granular" and "smooth" are unusual translations of the German "zah" and "fein" (French "coriace" and "fine"), but on reading the paper as a whole, these two English words appear to the reviewer to express most nearly the meaning of the author.

G.W.S.B.

19. Further Investigations of the Properties of Clay Suspensions. G.D. Hobson. J. Inst. Petroleum 26, p. 533, 1940. -

A number of clay suspensions have been examined in a capillary tube viscometer (pipette type with interchangeable capillaries; suction used) under different pressure gradients. This method was preferred to the use of the Hatschek concentric cylinder viscometer. Data were obtained on the relationships between rate of flow and pressure gradient, concentration and apparent viscosity and on the effects of stirring, heating, ageing, etc.

The systems were also examined by using cylinders and vanes in a torsion apparatus. As the torque was increased and before the yield took place, the system showed a small rotation roughly proportional to torque (elasticity). Near the yield point the elastic yield increased at an increasing rate. When the yield took place the deflection fell, being more rapid for the cylinder than for the vanes and usually faster the higher the yield value and the more thixotropic the mud. There are 39 references. E.W.J.M.