THE RHEOLOGY LEAFLET

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Publication
of the
SOCIETY OF RHEOLOGY

No. 3 October, 1937

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Address All Communications to Wheeler P. Davey, Editor of the Society of Rheology, School of Chemistry and Physics, The Pennsylvania State College, State College, Pennsylvania.

NINTH ANNUAL MEETING

The annual meeting of the Society of Rheology for 1937 will be held October 22-23 in Akron, Ohio. This meeting place is particularly appropriate because of the great rheological activity of the various rubber companies. We should have a good attendance, since Akron is very close to the "Center of the Gravity" of our membership. Headquarters will be in the Mayflower Hotel. The program is given on the next page of this leaflet and those following.

Technical sessions will be held Friday and Saturday mornings. On Friday afternoon members will have a choice of two interesting inspection trips. One will be through the tire plant of the Firestone Tire and Rubber Company, where all the major operations of tire manufacture will be demonstrated in logical sequence, from the crude rubber receiving room to final inspection of the finished tire. Emphasis will be placed on the rheological features of the processing.

The alternative trip will be through the Guggenheim Airship Institute and will stress the Laboratories, where a number of interesting experiments are being carried on in connection with the problem of lighter than air construction.

The annual dinner will be open to both members and non-members. Those of you have stopped at the Mayflower Hotel on previous trips to Akron don't have to be told that the dinner will be good.

Most of the Saturday morning papers will have to do with the rheology of rubber and closely allied substances. If you are interested in the rheology of substances entirely different from rubber, be sure to attend this meeting. You may pick up a few good and useful tips from the papers presented by your friends in the rubber game.

SOCIETY OF RHEOLOGY

NINTH ANNUAL MEETING

Hotel Mayflower, Akron, Ohio **October 22-23, 1937**

General Program

October 22

9:00 A.M. Registration

9:30 A.M. Program of Contributed Papers

1:30 P.M. Program of Contributed Papers

2:30 P.M. Trips to: Firestone Tire & Rubber Company
Guggenheim Airship Institute

7:00 P.M. Annual Banquet, Hotel Mayflower, followed by
Demonstration and Moving Pictures

October 23

9:30 A.M. Program of Contributed Papers

12:30 P.M. Luncheon and Business Meeting

Program Committee

H. R. Lillie, Chairman
E. C. Bingham
J. H. Dillon
E. O. Kraemer

Committee On Arrangements

J. H. Dillon, Chairman
W. F. Busse
A. M. Kuethe
J. W. Liska

SOCIETY OF RHEOLOGY

NINTH ANNUAL MEETING

Friday Morning, Oct. 22

9:00 A.M. Registration Begins

9:30 Society called to order, M. Mooney presiding,

Address of welcome.

Contributed Papers

9:50 A.M. 1. The Definitions of Rheology, by Eugene C. Bingham, Lafayette College, Easton, Penna.

The definitions have been published in the Leaflet. They were further discussed by the A.S.T.M. committee, of which several members of this Society are members. The resulting definitions have been submitted to the members for vote. It would seem to be the appropriate time for this Society also to take action.

10:10 A.M. 2. On the Viscosity and Plasticity of Disperse Systems. by M. P. Volarovich, Petrographic Institute of the Academy of Sciences, U.S.S.R.

The expression for plasticity, $\psi = \theta/\eta$ where θ is yield value and η is viscosity, is used in comparing the plasticities of a wide variety of materials. Rotation of cylinders, axial translation of cylinders and squeezing from tubes, are methods employed for measuring θ and η . Clays, flour doughs, printing paints and soap, give values of ψ in agreement with expectation, while in the case of peat the "plasticity" is unexpectedly high. Except for peat, ψ increases with temperature.

10:30 A.M. 3. Penetration of Oil Sprays by P. H. Schweitzer, Pennsylvania State College, State College, Penn.

This paper summarizes the major results of an extended study of the penetration of sprays such as those used in Diesel engines, atomizers, paint sprayers, and oil burners. A detailed report of the investigation is given in Bulletin No. 46, Engineering Experimentation Station, Pennsylvania State College.

The main findings of this investigation are as follows:

(1) The issue velocity can always be taken as 0.95 x $\sqrt{2gh}$, where h is the pressure head of the oil injected.

(2) The air resistance is proportional to the square of the oil velocity and to the first power of air density and is independent of the orifice diameter.

(3) The air resistance decreases with increasing oil viscosity, but is not sensitive to normal changes in specific gravity.

By a simple graphical method described in the paper the penetration can be determined for any combination of injection pressure, chamber air density, orifice diameter and oil viscosity.

Sprays of short duration have been investigated to obtain information on the building-up process. The test shows that the building-up is extremely rapid, the time required being so short that the spray in a Diesel engine is not influenced by the injection duration.

10:55 A.M. 4. Consistency of Eight Types of Vitreous Enamel at and near their Firing Temperatures, by W. N. Harrison, R. E. Stephens and S. M. Shelton, National Bureau of Standards, Washington, D. C.

The consistency of eight vitreous enamels, representing eight commercial types, was studied at and near the firing temperatures by means of a small rotation viscometer. Results are expressed in terms of viscosity for the enamels which behaved as simple viscous liquids and apparent viscosity for those not behaving as viscous liquids. Comparisons are made at constant torque in the apparatus, and the effects of variations in temperature and variations in type of enamel are reported. Also, for individual enamels the effect of varying speed of rotation at different constant temperatures is shown graphically.

11:20 A.M. Announcements.

11:25 A.M. Ten-minute Intermission.

11:35 A.M. 5. Motion Picture: The Yielding of Mild Steel, by A. Nadai, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Penna.

An extremely interesting film showing the formation of slip line patterns on the surface of hot rolled steel strips.

11:50 A.M. 6. Absolute Viscometer for Use at Extremely High Pressures, by H. E. Morgan and R. B. Dow.

12:10 P.M. 7. Rheological Properties of Asphalts.
V. Evaluation of Flow by Means of the Penetrometer

by R. N. Traxler and L. R. Moffatt, Barber Company, Inc., Maurer, N. J.

The method proposed by Thelen and improved by Rhodes and Volkmann, by which successive penetrations on a particular sample are used to calculate flow properties in absolute units, has been applied to a number of different asphalts. The values in poises obtained on viscous asphalts check with the data obtained by the falling coaxial and rotating cylinder viscometers described in previous papers. Data are given that make possible a comparison between the results obtained using viscometers and the penetrometer.

The penetrometer method appears to offer a rapid and satisfactory method of evaluating the flow characteristics of non-Newtonian bitumens (e.g., air-blown asphalts). The age-hardening characteristics of a number of asphalts from different sources and different methods of processing have been determined by this new method.

Friday Afternoon, Oct. 22

Contributed Papers

1:30 P.M. 8. The Fluidity of Normal, Iso-, and Unsaturated Compounds, by Eugene C. Bingham and Donald Stookey, Lafayette College, Easton, Penna.

Iso compounds are always more fluid and boil at lower temperatures and have a lower density than normal compounds. If studied at comparable temperatures the fluidities are identical. The fluidities are also found to be directly proportional to the corrected free volumes, $F/\phi = A$. The constant, A, for a given molecular weight, is to a first approximation independent of the chemical constitution. But on closer examination, there are polar effects. The value of A for an octyl alcohol is least when the alcoholic group is close to the middle of the carbon chain. A methyl radical, although not very effective, is nevertheless capable of lowering A, the rheolar free volume, most when near the polar group. In isomeric RCOOR' esters the rheolar free volume is least when R is larger than R'. In chlorides, bromides and iodides the increasing polarity causes the normal and iso compounds to diverge from each other.

2:30 P.M. Trips through:

(a) Firestone Tire and Rubber Company, or
(b) Guggenheim Airship Institute.

Friday Evening, Oct. 22

7:00 P.M. Annual Rheology Banquet, followed by:
Motion Pictures and Demonstration of Stress Phenomena in Glass as Observed Optically: by Howard R. Lillie, Corning Glass Works, Corning, N. Y.

Saturday Morning, Oct. 23

Contributed Papers

9:30 A.M. 9. Rigidity of Settled Pigment Layers in Paints, by E. L. McMillen and D. W. Glaser, Iowa State College, Ames, Ia.

The mechanics of pigment settling are discussed. It is concluded that the flocculated pigment structure at the bottom of the container must possess sufficient rigidity or yield value to support the net weight of all pigment above that level. This yield value is usually of the order of magnitude of 10,000 dynes per cm^2 or more, a much greater yield value than is observed in paints at painting consistency. Measurements on paints which have settled undisturbed for at least 5 years show rigidities of this order of magnitude to exist in the settled pigment layer. It is found that paints which develop this strength of plastic structure at moderate pigment concentration are much more easily reincorporated into the vehicle than those which develop such a strength only at high pigment concentration. This forms the basis for a proposed rapid test for settling tendency of pigments in various paint formulae.

9:50 A.M. 10. Fluidity and Reaction Rates, by Eugene C. Bingham, Lafayette College, Easton, Penna.

Symposium on Rubber

10:10 A.M. 11. Technical Aspects of Thixotropy, by A. Szegvari, American Anode Company, Akron, Ohio.

The study of Thixotropy originally started from observations made on coagulation phenomena. Later, it has been found that it has an influence on the flowing properties of many liquids.

The theoretical aspect of Thixotropy is interesting from the point of view of molecular interaction, and second, from the point of view of mechanics of flow. The latter is likely to be mathematically unduly complicated, but can be simplified for practical purposes.

From the practical point of view, four classes of Thixotropy can be distinguished considering the time factor and flow resistance factor of Thixotropy. The influence of these characteristics on systems like latex, rubber cements or paint will be discussed.

Measuring Thixotropy, the time factor and the flow resistance factor have to be considered. The latter can be determined only by an instrument where measuring itself does not influence the reading. A suggestion is made for a simple way of measuring and characterizing it in numerical terms.

10:40 A.M. Ten-minute Intermission.

10:50 A.M. 12. A General Theory of Large Elastic Deformations, by M. Mooney, U. S. Rubber Products, Inc., Passaic, N. J.

It is postulated that (1) the material is isotropic, (2) the volume change and hysteresis are negligible, and (3) the strain is proportional to the stress in two-dimensional shear in a plane previously deformed, if at all, only by uniform dilatation or contraction. It is deduced that the general strain-energy function, W, has the form

$$W = \frac{G}{4}\sum_{i=1}^{3}\left(\lambda_i - \frac{1}{\lambda_i}\right)^2 + \frac{H}{4}\sum_{i=1}^{3}\left(\lambda_i^2 - \frac{1}{\lambda_i^2}\right)$$

where $\lambda_i = 1 + e_i$, the e_i being the principal extensions. G is the modulus of rigidity, and H is a new elastic constant not found in previous theories of elasticity.

When $H = G/3$, approximately, the resulting stress-strain curve in simple tension agrees very accurately with the experimental curve obtained with soft vulcanized rubber up to 400% elongation.

This result finds an unexpected application in the theory of the molecular structure of rubber as related to its elastic properties. Given the experimental fact that the stress-strain curve in simple shear is approximately linear, the existence and location of the knee in the elongation curve is predicted, regardless of molecular structure. Hence, the only elastic peculiarities of rubber requiring explanation are the very small ratio of rigidity modulus to bulk modulus, and the large elastic deformation possible.

11:20 A.M. 13. Hardness of Rubber and Other Highly Elastic Materials, by Lewis Larrick, The B. F. Goodrich Company, Akron, Ohio.

Application of Hertz's theory of contact to the indentation of vulcanized rubber compounds by spherical indentors reveals that rubber obeys the laws of classical elasticity over a surprisingly wide

range of indentations. The law derived from the theory of infinitesimal deformations,

$$d = \frac{0.86 L^{\frac{2}{3}}}{E^{\frac{1}{3}} D^{\frac{1}{3}}}$$

(where E is Young's Modulus, L the load, D the diameter of the spherical indentor, and d the indentation, in consistent units) has been found valid for a number of compounds for indentations as large as ten per cent of the diameter of the indentor. This was true for high-gum stocks, pigmented compounds, and gas-black stocks. Above $d/D = 0.1$ the indentation increases more rapidly than the theoretical law predicts. This can be explained by the non-linearity of the stress-strain curve of rubber, or by the presence of elastic after-effect, permanent set, etc.

Since hardness is usually defined as resistance to penetration, the value of E, Young's Modulus, in the theoretical equation can be taken as a measure of the hardness for small deformations. Values calculated from the equation range from about 200 lb./sq. in. for soft compounds to greater than 1000 lb./sq. in. for hard stocks. The theoretical development shows that the least distance from the indentor to the edge of the sample and the thickness of the sample each should be greater than $10(d/D/2)$, which is in agreement with the experimental results.

Preliminary investigations show that hardness varies with temperature, but this variation depends upon the state of cure as well as upon the general nature of the ingredients incorporated in the compound.

11:50 A.M. 14. Gustiness Measurements and Their Application to a Method for Determining the Motion of Airships in Gusts, by A. M. Kuethe, Guggenheim Airship Institute, Akron, Ahio.

The spatial characteristics of atmospheric gusts (i.e., the dimensions of the air masses whose motions relative to the wind produce gusts) are being studied by means of autographic records of wind velocity and direction taken at the Naval Air Station at Lakehurst, N. J. Typical results are shown. The application of the results to a laboratory method for determining the motion of an airship passing through a gust is described. The setup is being prepared at the Guggenheim Airship Institute with financial assistance from the Navy Bureau of Aeronautics. The method utilizes a water tank across a section of which a stream of water, simulating a gust, flows. Water is used since the similarity condition postulating that the density of the model be near that of the fluid is difficult to satisfy in air. An airship model

immersed in the water and moved across the artificial gust is free to deflect angularly and laterally. Instanteous positions and inclinations of the model are registered. The results will provide a basis for determining the forces and moments acting on an airship during flight through gusts.

Saturday Afternoon, October 23

12:30 P.M. Rheology Luncheon, followed by:
Business Meeting
Adjournment

BOOK REVIEW

Elasticity, Plasticity, and **Structure of Matter** by **R. Houwink,** with a chapter on the Plasticity of Crystals by W. G. Burkers. 376 plus XVIII pp. $5.00 Cambridge University Press; the Macmillan Company, New York, Agent.

This work concerns itself with rheological aspects of different solid bodies of great technological importance. Only the first seventy odd pages are devoted to general considerations, growing out of the First Report on Viscosity and Plasticity, but with much closer attention to the effect of cohesive and repulsive forces resulting in solid structures of various kinds. Burgers in fifty-five pages presents briefly the conceptions of the nature of crystal flow developed by Schmid and Boas, Elam, Taylor, Smekal, etc. The remainder of the volume is devoted to the various individual types of solids in detail. There is a chapter on amorphous substances, including glass, resins and asphalt. The internal properties of each are first discussed and then the elastic and plastic properties are commented upon. Then follows a chapter on rubber, gutta-percha and balata, and after that cellulose and starch. Under proteins Houwink treats of gelatine and glue, casein, wool and silk, muscle, the urea-formaldehyde resins, and finally dough. Paints, lacquers, clay and at the close sulphur end the list. Everywhere the attempt is made so far as practicable to connect the chemical formula, the orientation and structure of the molecules with the observed elasticity and plasticity.

For some time it has been evident that industry needs just this sort of a volume, where the most recent views in regard to each material are assembled but where the theory consistent to all types of solids may be applied to each particular one. It is surprising that the author has been able to include so much in so small a compass, and if the work is as well received as it deserves to be, it may well serve as

an incentive for a treatise on a much larger scale. The book is written in good English, the plates are numerous and helpful and the errors are few. On page 276 the author states quite incidentally that the strength of gelatine is usually determined by pulling apart blocks which have been glued together. This may be the obvious way, but it is not the way that is workable with a high grade glue for the reason that the glue is stronger than the blocks, and, as is well-known, such a glue will in drying pull off the surface even from glass or porcelain. Hence the adhesive strength of a glue can better be determined by means of the gelometer and plastometer.

The reviewer raises a more important question as to the result of using the term **viscosity** as a fundamental property of solids, e.g., p. 349 where a **yield value** is involved. It seems as though inevitable confusion must necessarily follow this practice. The viscosity of a simple liquid is a true property of matter in that it is not dependent upon the value of the shearing stress and it is calculable by the use of the equation of Newton. The corresponding property of a solid, often called "the apparent viscosity" is not a fundamental property of matter since it is a function of the shearing stress, and no fundamental property can be calculated without a knowledge of the yield value, which is not considered in the formula for simple liquids. The terms **stiffness** or **immobility** already suggested as the reciprocal of the **mobility** offer a choice of names for the fundamental property in question, but if none of them prove acceptable we should try other possibilities.

Dr. Houwink introduces three different yield values, which are perhaps two more than will eventually be necessary. In clearly defining them and giving them symbols the defects in present usage are plainly evident.

Eugene C. Bingham

WHO'S WHO

Eugene C. Bingham. Born in Cornwall, Vt., Dec. 8, 1878. A.B. Middlebury College '99; Ph.D. Johns Hopkins University '05. Prof. of Chemistry, University of Richmond, '06-'15. Assistant Physicist, Bureau of Standards, '15-'16. Prof. of Chemistry, Lafayette College, 1916. Chemist, Bureau of Standards, 1918. Lieut. Col. C.W.S. He is the "Daddy" of the Society of Rheology and was the Editor of Journal of Rheology. When the Journal of Rheology was merged with Physics, he became Editor of the Society of Rheology, a post which he held until his physician advised that he lighten his load of duties. Research on fluidity, plasticity, viscosity, solubility.

J. H. Dillon. Born in Ripon, Wisconsin, July 10, 1905. A. B. Ripon College, '27; A.M. Univ. of Wisconsin, '28; Ph.D. Univ. of Wisconsin, '31. Assistant in Physics, U. of Wis. '27-'31. Physicist, Firestone Tire and Rubber Co., 1931-. Research on photoelectric properties of single crystals of metals, and on the physics (including the rheology) of rubber.

Howard R. Lillie. Born in Northeast, Pennsylvania, May 18, 1902. B.S. Allegheny College, '24; M.S. Univ. of Wisconsin, '26. Physicist, Research and Development Department (Physical Laboratory) Corning Glass Works, 1927. Research on viscosity, etc., especially of silicates.

A. Stuart Hunter. Born in Beachmont, Mass., August 28, 1897. B.S. Norwich College, '20; Ph.D. Johns Hopkins University, '24. Research Chemist, Metz Laboratories, '20-'25. Industrial Fellow, Mellon Institute, '25-'27. Physical Chemist, duPont Ryon Co., 1927-. Dr. Hunter was the first secretary of the Society of Rheology. When Mr. Wm. Buffman was no longer able to continue as Treasurer, the offices of secretary and treasurer were combined. Dr. Hunter's energy and sound advice contributed greatly in helping the Society to weather the critical periods of its early existence. He held the office of Secretary-Treasurer until ill health compelled him to resign, to the great regret of the whole Society. We rejoice that his health is now apparently restored.

BIOPHYSICS SYMPOSIUM

A special meeting devoted to the subject of biophysics will he held November 4, 5, and 6 under the auspices of the American Institute of Physics, in co-operation with the Eldridge Reeves Johnson Foundation for Medical Physics of the University of Pennsylvania. All sessions will be held in Philadelphia at the University. Information and admission cards may be obtained upon request addressed to the American Institute of Physics, 175 Fifth Ave., New York City.

RHEOLOGY ABSTRACTS

Both **Science Abstracts** and **Chemical Abstracts** have very kindly granted permission to reprint their abstracts of rheological articles in the Leaflet. They both have our heartiest thanks. We will avail ourselves of this privilege to provide rheology abstracts in future issues of the Leaflet.

THE SOCIETY OF RHEOLOGY

The Society of Rheology was founded in 1929 to further the study of the deformation and flow of matter. This purpose has been interpreted in the broadest sense, as covering types of deformation ranging from the viscous flow of fluids, through the plastic flow of soft substances, to the elastic deformation of solids. Rheology may be regarded as the science whose industrial application constitutes the field of materials testing.

Papers dealing with Rheology are presented to the Society at its annual meetings, and are published in the Journal of Applied Physics. All members of the Society receive the Rheology Leaflet, which is issued at irregular intervals, and which tells who is who and what is what in Rheology. They receive additional publications according to their class of membership, as indicated on the application blank appearing on the page following.

Membership is for the calendar year and new members receive the issues of the journal published prior to their applications. After September 1, application may be made, if desired, for membership to start January 1 of the year following.

The Society of Rheology is one of the member societies of the American Institute of Physics, and its members are entitled to subscribe to the following additional journals published by the Institute, at the rates shown:

	Domestic	Foreign
Physical Review	$15.00	$16.50
Reviews of Modern Physics	3.00	3.40
Journal of the Optical Society of America	6.00	6.60
Review of Scientific Instruments	1.50	2.00
Journal of the Acoustical Society of America	6.00	6.60
Journal of Chemical Physics	10.00	11.00
American Physics Teacher	3.00	3.30

APPLICATION

Mr. R. L. Peek, Jr., Secretary
The Society of Rheology
Bell Telephone Laboratories, Inc.
463 West Street
New York, New York

I hereby apply for membership in the Society of Rheology for the year ..... as follows:

[ ] Sustaining membership (including subscriptions to both **Journal of AppliedPhysics** and **R. S. I.** $25.00 or more

[ ] Regular membership (including subscription to **Journal of Applied Physics)** $6.00 (foreign, $6.50)

[ ] Associate membership (including subscription to **Review of Scientific Instruments)** $2.50 (foreign, $3.00)

Please also enter my subscription for the following additional periodicals published by the American Institute of Physics:

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