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FLOW OF POWDERS AND GRANULAR SOLIDS

British Society of Rheology Conference

Nottingham University, April 1965

Although there have been many symposia concerned with different aspects of powder science and technology, little attention seems previously to have been paid to the subject of the flow of powders (and granular solids) in its own right as a branch of rheology. We recall that Professor Dankwerts, in discussing methods of powder production and control at a symposium on powders in 1960¹ pinpointed "flow properties and flow behaviour" as an outstanding area of ignorance.

A Survey of *Rheological Research in Britain*² indicates that powder rheology is being studied by a number of university and college departments (e.g. of chemical engineering, mining, soil mechanics, metallurgy, ceramics, pharmacy, physics), government bodies, research associations (Cast Iron, Ceramic, Coal Utilisation, Non-Ferrous Metals, Paint, Whiting) and in nationalised and private industry in relation to such topics as flow from hoppers, fluidisation, mixing, settling, compaction, granulation, die filling (e.g. in powder metallurgy and automatic processes for granular plastics) tableting, transport of powdered fuel, etc. Very broadly, the states of interest are usually those of contacting particles (gravity flow, etc.), separated particles (fluidised flow) and transient states intermediate to these.

Gaseous fluidised beds have apparent fluid properties, e.g. density and viscosity. Some substances float on the surface of a fluidised bed whereas others sink. In 1957 an early worker in powder rheology, T. C. Daniels,³ attempted to use the falling sphere method of measuring the viscosity of a fluidised system. Some of the more recent interest for contacting particles has come from the field of soil mechanics, particularly the pioneering work of Jenike⁴ in the U.S.A.

Powders are not solids in the ordinary sense of the word nor are they liquids as commonly understood. They have a fundamentally non-homogeneous nature. In any sample, the solid particles may have a wide variety of sizes and shapes with air filling the interstices. The number of particles is too large for one to be able to arrive at mechanical properties by summing individual particles. Although some rheologists may object that powders are not continual, some of the difficulties appear to be overcome by applying the concepts of continuum mechanics, interpreted in a new light, together with some new concepts peculiar to the field. An important point is that powders can be considered as materials of variable bulk density.⁵

The present conference was opened by the President of the Society, Professor A. J. Kennedy (Department of Materials, College of Aeronautics, Cranfield) who in welcoming the delegates said that the Society had organised this meeting on the flow of powders and granular solids because it had considered that here was a definite field from a rheological viewpoint.

The first speaker, Dr. B. Neumann (*Fullers Earth Union Ltd., of the Laporte Group*), in an interesting introductory sketch of the outlines of the whole field, emphasised the relative importance of "derived" properties as compared with "inherent" properties, and the way in which particles become more cohesive as particle size is reduced; "skin depth" becomes more significant and gravity relatively insignificant. It was odd that in Eirich's 3-volume work on rheology⁶ there was little reference to flow of powders.

Gravity Flow, etc.

A paper on "*The Kinematics of the Flow of Powders and Bulk Solids*" by R. L. Brown and J. C. Richards (*British Coal Utilisation Research Association, Leatherhead*) dealt with a study of the flow of powders through apertures. Factors emphasised were dilatation, friction and surface of sliding. A model consisting of a single layer of ball-bearings flowing down an inclined plate had been studied; voidage measurements showed that dilatant waves pass upwards through the bed. Below the aperture the emergent stream forms a *vena contracta* and at the aperture there is a statistically empty space adjacent to the edges through which few balls pass. The angle to the vertical of the surface of sliding at the aperture had been measured (a) for a central slot (B_c), (b) for an edge slot adjacent to a vertical wall (B_e), (c) for a central circular aperture (B_s) and it had been found that $B_s < B_c \leq B_e$. This angle B was steeper than the angle of repose of a conical heap (A). The flow pattern of a powder approaching an aperture is convergent, powder is constrained by vessel walls or by the surface of sliding formed. At the aperture there is a free-fall arch, and the rate of discharge is determined by the conditions just above this arch. The evidence presented fully vindicated the Brown radial flow theory.⁷

The effect of cohesion of particles on flow was considered by T. M. Lowes and M. G. Perry (*Departments of Fuel Technology and Chemical Engineering, University of Sheffield*) in a contribution entitled "*Measurement of Cohesion in Powders*". A simple and rapid method was described, in which a plate carrying a cone of powder was tilted until shear occurred. Mathematical analysis of the shear conditions had given functions for the interparticle function and cohesion in terms of measurable cone parameters.

For strongly cohesive materials the measurements of shear plane angle is difficult but a technique giving reproducible values has been developed. Results obtained using sand and typical industrial powders were compared with values obtained by other techniques and the variation of cohesion with humidity had been investigated.

I. R. McDougall and A. C. Evans (*Department of Chemical Engineering, University of Leeds*) gave a paper entitled "*A Theoretical Equation for the Flow of Granular Solids from a Hopper*". Failure in shear is responsible for the inception of flow in granular solids but once the particles cease to be in contact with each other there is more resemblance to the flow of a fluid. Applied to the flow of cohesion free material from a horizontal aperture at the base of a hopper, these ideas were shown to lead to a relatively simple means of calculating a pseudo-pressure at the base of the hopper which can be substituted into a pressure-drop relationship of the Bernoulli type to give a theoretical equation for the flow rate from the aperture. The derivation depends on the treatment of the moving solids as a fluid and on the existence of an "active" condition in the material at the moment when movement commences. It was shown that the flow equation fitted in well with published data.

The paper "*Measurement of Stresses within Flowing Granular Materials*" by M. F. Handley and M. G. Perry (*Department of Fuel Technology and Chemical Engineering, University of Sheffield*) described stress measurements that had been made as materials flowed by gravity in small Perspex hoppers using a pressure-sensitive "radio pill". The radio pill is a miniature encapsulated radio transmitter about $\frac{1}{2} \times \frac{1}{8}$ inch (in medicine which was an original application, it can easily be swallowed). The pill used in the present work was pressure sensitive (pressure a linear function of frequency). The signals are picked up on a remote radio receiver. The experiments were carried out using sand, granulated pumice and limestone in various hopper shapes. Pressure distributions during filling of the hopper and emptying had been determined throughout the system. The technique had also been used to obtain flow patterns from within the measuring material and their variation with hopper shape. The experimental results were compared with the static value predicted by Janssen,⁸ Airy⁹ and others. The dynamic pressures were compared with the work of Delaplane,¹⁰ Reimbert,¹¹ and Lenczner.¹² Their agreement with Jenike's radial stress field was also discussed.

The flow of non-compacted granules or powders in the tablet machine hopper, with relevance to the unit dose of drug which is required to be dispensed, was discussed in a paper by J. A. Hersey (*Department of Pharmaceutics, The School of Pharmacy, London*) entitled "*Problems of Powder Flow in Tabletting Processes*". The various factors used to describe powder flow, such as angle of repose, interparticulate cohesion and friction, flow through apertures, bulk density and die fillability were considered. The effect of humidity, of

addition of fines or lubricants, and the use of commercially available apparatus for induced die feeding were included. During compression, powder flows in order to form a dense compact. Theories of this densification and the effects of entrapped air and die wall friction during compression and ejection of the tablet were examined and an attempt made to correlate non-uniformity in the final tablet with problems of powder flow.

Shear Cell Testing, etc.

Several speakers referred to Jenike⁴ and the shear cell or flow factor tester. *J. C. Williams and R. H. Birks (Bradford Institute of Technology)* outlined the background to this kind of approach in introducing their paper entitled "*The Preparation of Powder Specimens for Shear Cell Testing*". In their view, the only satisfactory method of measuring the flow properties of a cohesive powder is to examine the effect of normal loads on the shear stress needed to cause failure. For industrial powders this is usually carried out in a shear cell of the type designed by Jenike. In a series of tests it is essential that for each experiment the sample should be prepared in such a way that the powder is uniformly compressed to a known compaction level. Jenike's method for doing this had been found unsuitable in certain cases. Mr. Williams in delivering the paper however, paid great tribute to Jenike who started the present thinking. The work of Hvorslev¹³ and of Roscoe¹⁴ were also of considerable significance in the development of these ideas. The authors described a new method consisting of prestressing the powder under increasing loads and then examining a critical compaction level. After such preparations of specimens, three types of yield locus result, the meanings of which were discussed.

A new tensile testing apparatus developed at Warren Spring Laboratory has facilitated extension of the shears yield locus measurement made on the Jenike shear cell. This work was reported by *M. D. Ashton, R. Farley, D. C-H Cheng and F. H. H. Valentin* in a comprehensive paper entitled "*Some Investigations into the Strength and Flow Properties of Powders*" for more than 30 powders (including titanium dioxide, lithopone, Calofort, fine silica, etc.). Using yield loci at constant bulk density, determined with the Jenike apparatus and the Warren Spring tensile tester, power law relationships between tensile strength, cohesion and bulk density had been developed. The relationships between shear stress, normal stress and bulk density for powders had been represented by surfaces in a 3-dimensional space analogous to a similar concept developed in soil mechanics. It was considered that these relationships greatly simplify the laboratory measurements required for hopper design. In delivering the paper, Dr. Valentin emphasised the need for unified symbolism and terminology in the field of powder flow, etc.

Fluidised Flow

T. C. Daniels (*Department of Chemical Engineering, University College of Swansea*) reported recent developments of his work in his contribution entitled "*Measurement of Drag on Immersed Bodies in Fluidised Beds*". In a recently published paper¹⁵ he had reported measurement of the drag on metallic spheres falling through a dry gaseous fluidised bed and Binnie¹⁶ had proposed a dimensional analysis of the results. The apparent viscosity of the fluidised bed could be obtained from $R = V\rho d/\mu$ where V is the velocity of fall of the sphere of diameter d in a fluidised bed of apparent density ρ and R is the Reynolds number derived from the Schiller and Naumann¹⁷ equation relating R with drag. This viscosity had been found to vary inversely with a power of velocity of fall (or rate of shear) and also directly with a power of mean diameter of the particles forming the fluidised bed.

The general behaviour of air-solid jets issuing from the side of an air-fluidised bed through an orifice was considered in a paper by D. R. M. Jones and J. F. Davidson (*Department of Chemical Engineering, University of Cambridge*) entitled "*Flow of Particles from a Fluidised Bed through an Orifice*". From measurements of the mass flow of particles and of the jet trajectory, it had been possible to calculate the voidage fraction and the velocity of the particles where they leave the orifice. The efflux of air associated with the particles was also measured. A theory was presented to predict the particle velocities and the relative quantities of air and solid in such jets. Results from nozzles specially designed to reduce theoretical "inter-particle pressures" to a minimum were discussed. These measurements, together with orifice-plate jet measurements, were shown to confirm theoretical predictions.

Another paper, "*Flow Patterns on Fluidised Beds*" by B. Scarlett, M. J. Blogg and D. C. Freshwater (*Department of Chemical Engineering, Loughborough College of Technology*) dealt with liquid, as distinct from gaseous, fluidisation and described work showing that the solids flow pattern within a liquid fluidised bed of particles is such that two distinct regions exist. In the lower region adjacent to the fluid distributor the fluid flow pattern is influenced by the relative resistance offered to flow from point to point. At points of relatively low resistance, channels of liquid can exist which flow at velocities in excess of the particle transport velocities. The flow pattern of the particles in the lower region is one of bulk circulation, with upward motion in the channels of liquid and downward motion where the force on the particle due to the liquid flow is less than that due to gravity. In the upper region the liquid velocity attains a relatively smooth profile. Channels are non-existent and, within a range of superficial velocities determined by the transport velocity of the particles, the flow pattern is one of localised motion. In this region a uniformly fluidised bed is achieved.

A parallel plate bed had been used to investigate the solids flow patterns in a system of glass ballotini beads and water. The patterns produced at different water velocities had been studied for various sizes and size ranges of beads, and also for varying weight of charge. The effect of maldistribution of the fluid had been studied by artificially creating channels at the bed support. The existence of the two regions had been demonstrated by means of the variation of pressure gradient and also variation of local density as indicated by light transmission.

Lively discussions occurred both at and outside the formal sessions. The conference was generally adjudged to have been highly successful one and requests were received for another on an allied topic. Over 100 delegates participated, about two-thirds of whom were non-members of the Society (chemical engineers, powder technologists, etc.). The chairmen at the three sessions were respectively Professor Kennedy (President of the Society), Dr. Whitmore (Mining Department, Nottingham University) and Dr. Roscoe (Past President of the Society). The papers were of a high standard. It is hoped that they will be published in full in *Rheologica Acta* at an early date.

R. J. Cole

References

- ¹ Dankwertz, P. V., *Powders in Industry*. Symposium organised by Society of Chemical Industry—Surface Activity Group, September 1960.
- ² McLean, A. Y., and Hayward, A. T. J., *Rheological Research in Britain 1964*—A survey made jointly by the British Society of Rheology and the National Engineering Laboratory. N.E.L. Report No. 165.
- ³ Daniels, T. C., *Rheology of Disperse Systems*, ed. C. C. Mill, 1959—Proceedings of B.S.R. Conference, Swansea, 1957.
- ⁴ Jenike, A. W., Engineering Expt. Stat. Utah Univ., *Bull.* No. 108, 1961, **52**, 29; No. 116, **53**, 21; *Proc. ASTM*, 1960, **60**, 1168–1190.
- ⁵ Ashton, M. D., Cheng, D. C-H. and Valentin, F. H. H., Contribution to this conference.
- ⁶ Eirich, F. R., *Rheology, Theory and Application*, New York, 1958.
- ⁷ Brown, R. L., *Nature*, 1961, **191**, 458.
- ⁸ Janssen, H. A., *Zeit. Ver. Ingner*, 1895, **39**, 1045.
- ⁹ Airy, W., *Proc. Inst. Civ. Eng.*, 1897, **131**, 347–358.
- ¹⁰ Delaplain, J. W., *J. Amer. Inst. Chem. Eng.*, 1956, **2**, 127–138; 371.
- ¹¹ Reimbert, M., *Travaux*, 1958, **38**, 780.
- ¹² Lenczner, D., *Structural Engineer*, 1963, **41**, 289.
- ¹³ Hvorslev, M. J., *Ingridsensk. Skr. A.*, 1937, No. 45, 159.
- ¹⁴ Roscoe, K. H. *et al*, *Geotechnique*, 1958, **8**, 22–53; 1963, **13**, 12.
- ¹⁵ Daniels, T. C., *J. Mech. Engng. Sci.*, 1962, **4**, 103.
- ¹⁶ Binnie, R. M., *Trans. Inst. Chem. Engrs.*, 1963, **41**, 231.
- ¹⁷ Schiller, L., and Naumann, A. Z., *Ver. Dtsch. Ing.*, 1933, **77**, 318.

Nomenclature and Symbols in Rheology

The following request was received by the Editor early in March.

"The Victorian branch of the B.S.R. has appointed a sub-committee to study the nomenclature and symbols used in the field of rheology. The ultimate aim is to prepare a list of recommended rheological terms and publish it in conjunction with the Standards Association of Australia.

"The first task of the sub-committee was a literature search.

"The sub-committee would be anxious to hear from members about any previous or current attempts to standardise rheological terminology. Any suggestions that would be of help in our work would also be welcome.

"Please contact Mr. K. R. Hall, c/o Chemical Research Laboratories, C.S.I.R.O., Box 4331, G.P.O., Melbourne, C.I., Victoria, Australia."

The Bulletin of the Groupe Française de Rheologie, received only a few days previous to the above note, contained 14 proposed definitions of rheological terms, with a further seven definitions following in the next issue.

The definitions, which were of a provisional nature, covered terms such as stress, strain, shear, slip, elasticity and recovery, and were to be submitted to the Council of the Groupe at its next meeting. When a final form has been agreed, the definitions, together with an English translation, will appear in this Bulletin, for the benefit of members of the Society who read papers in the original French. Copies of the provisional definitions are obtainable on request from the Editor.

In addition to the above, but probably not finally, Dr. Scott-Blair and Professor Reiner are collaborating in the preparation of a monograph on the subject of nomenclature and symbols, which will form part of Volume IV of Eirich's "Rheology", and will also be published separately.

Perhaps other interested parties will let it be known if they are preparing surveys of a similar nature.

Errata

The following corrections should be made to the paper "Some Mistakes in Rheology", by Dr. R. Roscoe, which appeared in Bulletin No. 1, 1965.

- p. 6 Last line: for "liquid" read "solid".
- p. 7 Fig. 4: Confining pressure should be 10,000 atmospheres.
- p. 9 Third paragraph: for " RT " read " R "; for " E/RT " read " E/R ".
- p. 10 Second paragraph, line 3: the last symbol should be the square root of T .
- p. 12 First equation: a factor of 2 should be inserted on the right-hand side.

Dr. Herbert Leaderman

The death occurred on February 20th, 1965, at the age of 51, of Dr. Herbert Leaderman, the distinguished rheologist and polymer physicist. Despite being cruelly afflicted by arthritis for several years Dr. Leaderman had continued his theoretical studies right up to the time of a fatal heart attack.

Dr. Leaderman was born in London, and graduated at Cambridge University in 1934. He subsequently moved to M.I.T., where he was awarded a Ph.D. in 1941. The publication in 1943 of "Elastic and Creep Properties of Filamentous Materials" marked a milestone in the study of the mechanical properties of viscoelastic materials, and laid the foundation of much recent work in the field. For his services to rheology Dr. Leaderman was in 1955 awarded the Bingham Medal of the (U.S.) Society of Rheology.

BIBLIOGRAPHICAL RECORD OF THE SCIENTIFIC PROCEEDINGS OF THE SOCIETY
(including Joint Meetings with other Organisations)

I. As the British Rheologists' Club

<i>Ser. Ref.</i>	<i>Year</i>	<i>Title</i>	<i>Venue</i>	<i>References</i>
a	1944	General Rheology	Oxford	<i>Essays in Rheology</i> , Pitman & Sons, London, 1947. (103 pp.)
b	1945	Rheology of Petroleum Products	London	<i>J. Inst. Pet.</i> , 1945, 31 , 239-338.
c	1946	Principles of Rheological Measurement	London	<i>The Principles of Rheological Measurement</i> , Nelson & Sons, London, 1949. (214 pp.)
d	1948	Rheology of Textiles	Leeds	<i>J. Text. Inst.</i> , 1948, 39 , 229-308.
e	1949	Recent Developments in Rheology	Bristol	<i>Some Recent Developments in Rheology</i> , ed. Harrison, V. G. W., United Trade Press, London, 1950. (147 pp.)
II f	1950	Physics of Lubrication	Manchester	<i>Brit. J. Appl. Phys.</i> , Supp. No. 1, 1951. (104 pp.)

II. As the British Society of Rheology

1	1951	Rheology in the Confectionery Industry	London	—
2	1951	New Developments in Viscometry	Birmingham	Mardles, E. W. J., <i>Nature</i> , 1951, 168 , 108.
3	1951	Dilatancy in Sands and Other Granular Materials	London	—
4	1951	Rheology of Films and Surfaces	Exeter	Mardles, E. W. J., <i>Nature</i> , 1951, 168 , 945.
5	1952	Abrasion and Wear of Materials	London	(i) <i>Iron & Coal Trades Rev.</i> , 1952, 261-63. (ii) Feltham, P., <i>Nature</i> , 1952, 169 , 450.
6	1952	Emulsions and Films	Sheffield	Lawrence, A. S. C., <i>Nature</i> , 1952, 170 , 232.
7	1952	Tack and Adhesion	London	—
8	1952	Sprays, Dopes and Aerosols	Cambridge	—

<i>Ser. Ref.</i>	<i>Year</i>	<i>Title</i>	<i>Venue</i>	<i>References</i>
9	1952	Plasticity	Southampton	Kennedy, A. J., <i>Nature</i> , 1952, 170 , 875.
10	1953	Rheological Instruments and Apparatus	London	—
11	1953	Elasticity in Liquids	Durham	<i>Nature</i> , 1953, 171 , 778.
12	1953	Mixing of Thick Liquids, Pastes and Slurries	London	Wookey, N., <i>Nature</i> , 1953, 172 , 846.
13	1953	Methods of Presenting Rheological Results and their Relations	London	Scott-Blair, G. W., <i>Nature</i> , 1954, 173 , 156.
14	1954	Friction in Relation to Rheological Properties	London	Tabor, D., <i>Nature</i> , 1954, 173 , 899.
15	1954	Rheology in Mechanical Engineering	East Kilbride	<i>Nature</i> , 1954, 174 , 201.
16	1954	Visco-elasticity in Solids, Emulsions and Solutions	London	—
17	1955	Relaxation and Flow in Glasses	London	(i) <i>Nature</i> , 1955, 175 , 747. (ii) <i>Journ. Glass Tech.</i>
18	1955	Visco-elastic Behaviour	Newcastle	<i>Nature</i> 1955, 176 , 61.
19	1955	Surface Rheology	Exeter	Mardles, E. W. J., <i>Nature</i> , 1955, 176 , 819.
20	1956	Rheology of Proteins	London	(i) Ward, A. G., <i>Nature</i> , 1956, 177 , 516. (ii) <i>Bull. Brit. Soc. Rheol.</i> , 1956, No. 46.
21	1956	Rheological Research in the Textile Industry	Manchester	—
22	1956	Extrusion and Rolling Processes	Sheffield	Hardwick, D., <i>Nature</i> , 1956, 178 , 1158.
23	1957	Rheological Control of Industrial Processes	London	—
24	1957	Rheology of Elastomers	Welwyn	(i) Lodge, A. S., <i>Nature</i> , 1957, 180 , 75. (ii) Mason, P., and Wookey, N. (ed.), <i>Rheology of Elastomers</i> , Pergamon Press, 1958.
25	1957	Rheology of Disperse Systems	Swansea	(i) <i>Nature</i> , 1957, 180 , 957. (ii) Scott-Blair, G. W., <i>Nature</i> , 1960, 185 , 878. (iii) <i>Rheology of Disperse Systems</i> , Pergamon Press, 1959.

Ser. Ref.	Year	Title	Venue	References
26	1958	Accurate Measurement of Viscosity	London	(i) Mardles, E. W. J., <i>Nature</i> , 1958, 182 , 438. (ii) <i>Rheol. Abs.</i> , 1958, 1 , (2), 24-29. (iii) <i>J. Inst. Pet.</i> , 1958, 44 , 394-400.
27	1958	Rheology of Road Materials	London	—
28	1959	Flow, Fatigue and Failure	Leeds	<i>Rheol. Abs.</i> , 1958, 1 , (4), 34-45; 1959, 2 , (1), 44-47.
29	1959	Dynamical Flow Properties of Liquids and the Glassy State	London	—
30	1959	Flow Properties of Blood and Other Biological Systems	Oxford	(i) <i>Rheol. Abs.</i> , 1959, 2 , (4), 27-50. (ii) Scott-Blair, G. W., <i>Nature</i> , 1959, 184 , 1539-41. (iii) Copley, A. L., and Stainsby, G. (ed.), Pergamon Press, 1960.
31	1960	Lubrication; Dispersions; Methods and Concepts	Manchester	(i) <i>Rheol. Abs.</i> , 1960, 3 , (1), 29-34. (ii) Tattersall, G. H., <i>J. Mech. Eng. Sci.</i> , 1961, 3 , 378.
32	1960	Rheology of Polymers	Swansea	<i>Rheol. Abs.</i> , 1960, 3 , (3), 21-36.
33	1961	Theoretical Rheology	Reading	<i>Rheol. Abs.</i> , 1961, 4 , (1), 22-25.
34	1961	Rheological Techniques	Llandudno	(i) <i>Rheol. Abs.</i> , 1961, 4 , (3), 24-30. (ii) <i>Lab. Practice</i> .
35	1962	Temperature Dependence of Viscosity of Near-Newtonian Liquids	Battersea	<i>Rheol. Abs.</i> , 1962, 5 , (1), 35-36; (2) 33-36.
36	1962	Rheology of Emulsions	Harrogate	(i) <i>Rheol. Abs.</i> , 1962, 5 , (3), 30-35. (ii) Sherman, P. (ed.), Pergamon Press, 1963.
37	1963	Visco-elastic Properties of Organic and Inorganic Glasses.	Sheffield	(i) <i>Rheol. Abs.</i> , 1963, 6 , (1), 31-35. (ii) <i>Phys. & Chem. of Glasses</i> , 1963, 4 , (4), 117-167.
38	1963	Rheological Properties of Clay and Fine Powder Suspensions	Keele	<i>Rheol. Abs.</i> , 1963, 6 , (3), 91; (4), 120-21.

<i>Ser. Ref.</i>	<i>Year</i>	<i>Title</i>	<i>Venue</i>	<i>References</i>
39	1964	Rheology of Paint and Allied Products	Teddington	<i>Rheol. Abs.</i> , 1964, 7, (1), 41-48; (2), 73-75.
40	1964	Rheogoniometry	Exeter	(i) <i>Rheol. Abs.</i> , 1964, 7, (3), 106-108; (4), 139. (ii) <i>Bull. Brit. Soc. Rheol.</i> , 1964, No. 4.
41	1964	Teaching of Rheology	Exeter	(i) <i>Rheol. Abs.</i> , 1964, 7, (3), 109-111. (ii) <i>Bull. Brit. Soc. Rheol.</i> , 1964, No. 4. (iii) <i>Bull. Inst. Phys.</i> , 1965, 16, (3), 95-103.
42	1965	Flow of Powders and Granular Solids	Nottingham	(i) <i>Bull. Brit. Soc. Rheol.</i> , 1965, No. 2. (ii) To be published.

III. International Congresses on Rheology

<i>Ser. Ref.</i>	<i>Year</i>	<i>Venue</i>	<i>Reference</i>
1st	1948	Scheveningen (Holland)	<i>Proceedings of the (First) Int. Conf. Rheology</i> , North Holland Pub. Co., 1949. (641 pp.)
2nd	1953	Oxford (U.K.)	(i) Scott-Blair, G. W., <i>Nature</i> , 1953, 172, 487. (ii) Harrison, V. G. W. (ed.), <i>Proc. Second Int. Conf. Rheol.</i> , Butterworths, 1954. (451 pp.)
3rd	1958	Bad Oeynhausen (Germany)	<i>Rheol. Acta.</i> , 1958, 1.
4th	1963	Providence, R. I. (U.S.A.)	Lee, E. H. (ed.), <i>Int. Rheol. Cong. (4th) Proc.</i> , J. Wiley (to be published).

The Hon. Secretary is grateful to the present and past members of Committee who have assisted in compiling the index, and would appreciate hearing of errors and omissions from any member of the Society.

Notes and News

Mr. J. F. Hutton, a former Editor of this Bulletin, delivered a paper on "The Fracture of Liquids in Shear" before The Royal Society at Burlington House on April 29th, 1965. The concept that visco-elastic liquids will ultimately fracture under the influence of shearing forces was developed to explain instabilities observed at very low Reynold's numbers in both capillary tubes and cone and plate viscometers.

The Annual Conference of the Groupe Français de Rheologie was held in Paris, May 20th, 1965, on the topic of "The Rheology of Two-phase Systems". Members of this Society were invited to contribute to the proceedings, and in response to the invitation Dr. G. W. Scott-Blair read a paper, written in conjunction with Mr. J. H. Prentice, on "The use of a double logarithmic equation to describe the flow of suspensions as typified by dairy creams at low temperatures".

The eightieth President of the Institution of Mechanical Engineers is Mr. H. N. G. Allen, C.B.E., M.A., Joint Managing Director of W. H. Allen, Sons and Co. Ltd. Mr. Allen is also Vice-Chairman of the College of Aeronautics, Cranfield, and a member of the Steering Committee of the National Engineering Laboratory.

The Society of Glass Technology will hold a conference, which includes a symposium on Fuel and Power, at Llandudno, September 22nd-25th, 1965.

Arrangements are being made for the Golden Jubilee celebrations of the Society, to be held in Sheffield, November 8th and 9th, 1966.

Details of both meetings can be obtained from the Hon. Secretary, 20 Hallam Gate Road, Sheffield 10.

Details of the following meetings are obtainable from the Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1:

A joint convention of Environmental and Mechanical Engineers will be held at Manchester from September 6th-10th under the general title of "Machines for materials and environmental testing".

The Thermodynamics and Fluid Mechanics Group of the Institution will hold a convention in Liverpool during April 1966.

The Third International Heat Transfer Conference will be held in Chicago, U.S.A., August 8th-12th, 1966. Papers are being sought on the broadest possible basis on both fundamental and applied aspects of heat transfer and accompanying mass transfer. Abstracts of proposed papers should be sent by July 1st to R. J. Millson, 1 Birdcage Walk, London, S.W.1.

The 36th Annual Meeting of the (U.S.) Society of Rheology will be held at Case Inst. of Technology, Cleveland, Ohio, October 25th-27th, 1965. Details may be obtained from the Program Chairman, Stephen Prager, Dept. of Chemistry, Univ. of Minnesota, Minneapolis.

New Members

NAME AND ADDRESS	INTERESTS
H. A. Barnes, 17 Hill St., Ystrad Mynach, Glam.	Viscoelasticity, blood.
Miss W. M. Cooper, 193 Woodfield Rd., Harrogate, Yorks.	Polymer melts.
B. Ellis, 24 Brandreth Rd., Pen-y-Lan, Cardiff.	Polymers.
G. P. Graham, 10 Cours de la libération, Grenoble (Isère), France.	
J. F. Richardson, Dept. of Chem. Engng., Univ. College, Swansea.	
D. N. Samuel, Kings Grove, Barton, Cambridge.	Instruments, polymer solutions.
R. A. Scott, The Cementation Co. Ltd., Denham Way, Rickmansworth, Herts.	Clay, slurries, hydraulic cements.
M. H. Yates, 2 Copse Rd., Redhill, Surrey.	Clay minerals.
M. M. Young, Faculty of Engng. Sc., Univ. of Western Ontario, London, Ontario, Canada.	Suspensions, polymers, biorheology.

The following have been elected members of the Victoria, Australia, branch:
J. L. Cohen, J. D. Gibson, A. W. Stephenson.

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ANNUAL CONFERENCE 1965

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