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THE
BRITISH SOCIETY
OF RHEOLOGY

BULLETIN — No. 1, 1964

Hon. Secretary :

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Hon. Editor (Bulletin) :

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RHEOLOGY IN THE PRINTING INDUSTRY—I

by E. W. J. Mardles

The printing industry, one of the ten biggest, is also one of the oldest; nine books of Confucius were printed in China, 932 A.D., and wood-cut prints of Buddhist manuscripts, the oldest examples of printing in the world's history, were made 77 to 764 A.D.

Now, with highly mechanised production and partial automation, cheap printing and art reproductions are the sequel to the utilisation of facilities afforded by modern engineering sciences, by the dyes and new materials discovered by the chemist, aided by knowledge of the colloidal state and surface properties, and by the recent advances of scientific discovery and invention in general. The past 50 years have seen impressive progress in printing machine design and processes; the early craftsmanship continues as evidenced by the P.A.T.R.A. research programme which includes a fundamental study of print quality involving subjective judgments and how they can be supported and extended by scientific testing.

Recent advances in printing science are described mainly in a steady flow of publications from printing research institutes; for example, in the current issues, 1963, of the Bull. Tech. Assn. of Graphic Arts, Tokio, are given examples of powder screen printing on textiles, metals, etc., using static electricity and magnetic brush distributors, and descriptions are also given of the preparation of printing plates by electro-photographic transferring. In an article in the Printing Review, Aug., 1963, entitled "Art work transmitted electrically—a Canadian first," a method of transmitting art work in $6\frac{1}{2}$ minutes is described. The craftsman, once apprenticed to produce a handsomely bound book, has now to specialise and possess a scientific knowledge essential to the right control of complex and costly machinery. He must have a working knowledge of the ink-paper-machine relationship, a 3-horse chariot manageable only with great skill and experience; the ink and the paper may both be suitable but if the ink flows too freely because, say, the machine is out of adjustment due to a small temperature rise, the quality of the print suffers. The sensitivity of the triple harmony required is such that it can be easily upset; for example, stopping and restarting the machine in colour printing might change the colour tone. The preparation of colour separation by photo-electric systems has attracted attention, a technique which supplements human skill by objective measurement and replaces routine work by automatic control.

Some of our members will have happy memories of discussions at the Smithfield P.A.T.R.A. research laboratories towards the end of

the war on tack, adhesion, viscometry, etc., when rheological studies were introduced to elucidate printing problems. Although much has been done rheologically since then, a survey of the literature up to date raises more questions than answers. In summing up at a conference on the flow properties of inks, paints, adhesives, etc., Cleveland, 1959, Bobalek stated that the general conclusion was inescapable that the theory of flow is yet undeveloped and imperfect so that there was poor co-ordination between rheology and the art of flow control, a view reminding one of Pryce-Jones's remark that it is very improbable any rheologist of repute would claim that he has made satisfactory observations when using only one type of rheometer. A co-operative study of the limitations of rheometers, their repeatability and reproducibility accuracy, is long overdue.

To the objection that rheology is far too complex a science and too costly for industrial testing, Henry Green made a five-point reply in 1956. He pointed out the great value of rheology in research in the development of new materials and processes, in correcting and improving older techniques and for establishing standard procedures. Although physicists and chemists are employed in research and control in the manufacture of inks, adhesives, etc., it is often stated that the formulation of the products is based on trial and error depending upon the formulator but it is admitted that broad knowledge and expert ability are required in the formulation of even the simplest types of ink. The lithographer expects the ink he receives to have the correct "body" and tack suitable to the printing sequence, while the ink maker complains that he has little or no control over the way his ink is used, that he has to tailor his products to fit the press and paper and that he is usually blamed for defects in printing quality.

Difficulties in the press room arise when thinners or various additives are added to the ink to obtain the desired consistency and tack, which is usually estimated by the flick of a finger from a blob of ink. Deterioration in print quality may occur from this procedure of additions, especially if used with the wrong ink. Apps, 1963, instructing on the use of gravure inks states that the settling of solids in the ducts or fountains may be reduced by agitation but this may cause frothing and skinning, a difficulty requiring further treatment with additives. The problem of storage changes in printing inks has been studied by chemists of the Soviet bloc; Shakhkel'dyan comments on the stability test of the All-Union Standard 7346-55, that there was difficulty in interpreting the results with the cone penetrometer and was at a loss to know how to "work" the samples for the test. Chomikovski and Reh binder investigated the problem of the variability of the properties of printing inks with time from the standpoint of colloidal and surface chemistry. They measured the surface properties of carbon blacks in terms of liquid imbibition, particle size and size distribution, sedimentation, electrical properties, etc. They considered the most important technological properties of inks, namely, transparency, colour

shade, rheological properties, etc., to depend in great degree on the state of dispersion and stability of the inks. They expressed the stability in terms of attraction between particle surface and the molecules of the vehicle and considered that the technical difficulties of dusting, deformation of the ink layer, filling of the screen during printing, etc., arose from coarseness of dispersivity of the pigment or from causes related to the instability of the inks.

C. C. Mill, P.A.T.R.A., gave an outline of the rheological life of a printing ink for letterpress or lithographic work, from the container to the printed image, at the Exeter Conference of the B.S.R. on surface properties. He pointed out the major requirements of these inks and spoke of interesting flow phenomena observed, for example, if two rollers rotate in contact. The ink collects in a series of parallel ridges which are dispersed only if at least one roller in the system has a reciprocating action. The origin of these ridges is important as they occur in varnish coating, tin plating, etc., and an explanation would throw some light on the complex problem of tack.

A. Voet at the First Rheological Conference, Holland, described ink flow in the press and pointed out that the rheological demands for a lithographic ink followed an exceedingly complex pattern and that D/τ (shear rate/shear stress) diagrams should include results from very low shearing stresses to as high as 10^6 dynes cm^{-2} to cover ink transport in duct and fountain and in the roller system.

R. F. Bowles has enumerated various laboratory tests for studying the rheological behaviour of printing inks, in particular, with regard to the behaviour in the duct, batch control of consistency, efficiency of grinding processes and mechanism of ink distribution.

Advertisements for printing inks have sometimes stated that the inks have the right amount of thixotropy; presumably this refers to bulk rheology indicating that they will not "hold back" from the ink roller distribution systems. Thickened inks are troublesome in this respect but in rapid motion with film thicknesses of the order of 20 microns their rheology is not the same as for the bulk material. Sjodahl and others have stated that although viscosity and yield value measurements are important, they are inadequate by themselves to explain all ink behaviour in the press. Similarly Enya (Nippon Insatsu Gakka Ronbunshu, 1960) found no correlation of yield value and apparent viscosity or any rheological factor of the bulk material which seemed to influence ink transference; several workers have said that experimental work is required to measure the "wetting" properties of an ink although its rheological requirements are correct. On the other hand, Gudova, Kozarrovilski and Mikhailus, 1962, who studied three representative inks found that the structural differences in the bulk inks clearly influenced their behaviour in their course through the machine. The slopes of the flow diagrams enabled an understanding and prediction of the practical difficulties likely to be encountered in the press during distribution on the feed rollers and in the transfer of

the impression to paper. Viscosity measurements at higher rates of shear have been frequently reported to correlate better with the roller coating of paper with adhesives or with ink than those at lower rates of shear, but undoubtedly the problem of ink film splitting during transference involves other factors than rheological ones, such as receptivity by the paper, adhesion and wetting rates. There remains a big field of research relating to the rheology of thin films pressure-laid on the surface of paper, say, in the fiftieth of a second.

Kosarovitsky (Moscow All-Union Sc. Res. Inst. for the Polygraphic Ind., 1962) emphasises the importance of the paper on printability. Under pressure, as when a well-contoured type face of half-tone dots is impressed on paper, the ink may be squeezed out if the paper is too hard and if too soft mottling may occur and the paper permanently indented. He considers that the micro structure of a paper governs printability and he lists structure of surface, mechanical structure and ink receptivity as the other governing factors.

There is no universal ink for any printing process that excludes every failure and inks must be selected individually and adapted in accord with the prevailing conditions depending on stock and equipment; the ink plays a special role inasmuch as any discrepancy or defect becomes visible and recognisable through the printed image but it does not mean that the ink is the cause of failure—spongy and imperfectly-shaped rollers may be the cause. Hard papers require an ink of different rheological properties from those for softer papers and this has to be worked out by special methods of test. Scientific investigations on the manner in which an ink film is laid on a surface and consequent variations in properties have not progressed far.

In a current trade journal it was reported that inks for use with papers of different smoothness and texture have not yet been produced, neither is the rheology of such inks known whereby the holes and crevices of paper are satisfactorily “bottomed”. If the ink film is not properly laid on the surface but is distributed in thin films on the dots and in thicker films where the ink has filled the crevices, a speckled appearance can result because the white of the paper will show through the thin ink film on the projections of the paper. M. Hartmann who has studied extensively the ink-paper relation has found the drying rate of ink impressions varies a good deal for the same ink on different papers.

There is a sequence in consistency from the thickened inks for letterpress and lithography via the platen press, the cylinder press, the offset press, the reel-fed rotary and offset processes to rotogravure and flexographic printing with its near liquid inks. However, it is known that results obtained in ink transfer studies are not in direct relation to the consistency of the ink but agree more with the tack of the inks as indicated by inkometers (tack meters).

The little-understood rheological property of an ink known generally as tack is in one respect not unlike the other little-understood rheological property thixotropy, since each to give correct printing according to

advertisement must be just right, not too little or too great. Tack constitutes quite a problem area especially in lithography which, being more versatile and generally less costly than letterpress and gravure, is growing rapidly. Tacky inks require both papers with high pick strength, i.e., resistance to surface rupture with tearing of fibres, and also complex ink distributing systems to improve the ink flow. New printing plates requiring less damping and systems with improved damping, have made possible the use of inks of lower tack. Coated papers with greater pick resistance are also being made.

The inks must not only be right rheologically but faster drying times are required and the inks must not contain undesirable ingredients which in the presence of moisture cause scumming, binding, tinting and piling. Baysung Hsu, P.A.T.R.A., 1963, has studied the factors which influence a paper's printability and has found regarding tack that for a given paper the critical tack stress, the minimum stress required to cause paper surface picking in printing, is constant whatever the liquid or printing speed. During impression ink or a colloidal dispersion may flow into a paper as a single phase but after impression filtration occurs.

Tackiness is a tiresome fault. The short paper fibres with china clay released from the paper surface by the too tacky ink and aggravated by any rubbing action on the surface, build up on the offset blanket and plate into the inking system. The ink becomes stodgy and there results a general lack of contrast in the print—the half-tone dots printing as solids.

It comes rather as a surprise that rule-of-thumb inks print so tolerably well and consistently, considering the enormous diversity of materials used in their manufacture and their wide range of consistency.

The whole gamut of rheological properties and behaviour could be found among printing materials, inks, adhesives, papers, plastic rollers, packings, etc., and it certainly is a poser to say with conviction which particular rheological property or combination of properties is responsible for printing quality. The preparation and use of adhesives seems to be an art rather than a science, and information on the rheology of the materials and their application is scanty.

Letter to the Editor

Dear Editor,

May I offer the following comments on Dr. Mardles' article in Bulletin No. 3, 1963.

- (1) I should have thought it worth while to keep the term "dynamic viscosity" when one wants to be sure that it is understood that one is not referring to the "Kinematic viscosity"; otherwise, use simply "viscosity".
- (2) "Relative increase in viscosity" is certainly more correct than "Specific viscosity" but it is longer and the latter term is now so very well-known—it would be hard to change.
- (3) I like the idea of "Einstein coefficient" in place of "intrinsic viscosity" or "limiting viscondex". I wonder if it matters that Einstein finally settled on 2.5 as a fixed value? Perhaps not—he knew the limitations of his own equation and it was not long before values other than 2.5 were proposed. I have often pressed Dr. Treloar's point that it would be dimensionally much better to quote concentration as a numeric but people just won't do it!

Sincerely yours,

G. W. SCOTT BLAIR.

National Institute for Research in Dairying
Shinfield,
Reading.

Elastic Liquids

The Academic Press is to publish early in 1964 a book entitled "Elastic Liquids". The author is a member of the Society, Dr. A. S. Lodge, Senior Lecturer in Rheology at Manchester University. The brochure states that the book is an introduction to phenomenological theories of visco-elastic materials subjected to large changes of shape. "Using elementary vector analysis, a simple mathematical technique is developed from first principles. . . . Detailed consideration is given to large elastic recovery, stress relaxation, the Weissenberg effect and other properties which are of special interest in relation to polymeric materials. Tensor analysis is not used until the final chapter, where the treatment is generalised for non-uniform conditions."

This book will be reviewed in Rheology Abstracts as soon as possible.

TEWKSBURY SYMPOSIUM ON FRACTURE, 1963

This Symposium was held in Melbourne during August and was made possible through a bequest of the late Mr. P. W. Tewksbury. The purpose of the Symposium was "to bring together scientists studying fracture of various materials and engineers concerned with the practical implications of these studies". Twenty-two invited papers were presented and discussed and, in addition, Professor A. H. Cottrell delivered the Tewksbury Lecture "Mechanisms of Fracture". All the papers and a summary of the discussion will be published in a cloth-bound volume; the secretary of the Symposium Committee was Dr. C. J. Osborn, Metallurgy Department, University of Melbourne, Parkville, N.2, Victoria, Australia.

This is the third international conference on fracture to be held in four years. The first, at Swampscott¹ in 1959 was on atomic mechanisms of fracture and was mainly concerned with crystalline materials, particularly metals; brittle and cleavage fracture, together with fatigue, claimed the lion's share of the proceedings. The second, in 1962, at Lake Wilderness (Seattle)² was limited to crystalline materials but covered all aspects of fracture; no striking advances appeared to have been made during the two years since Swampscott³. The Tewksbury Symposium covered a broader field of materials, as the following session headings will show: metallic materials (ductile, brittle, fatigue and creep fracture); non-metallic materials (MgO, glass and concrete); organic materials (wood, paper and plastics); engineering structures; soils and rocks; comminution of minerals; machining of materials (metal, wood and coal).

With such a diversity of materials, it is obviously unlikely that the discussion could be unified in a simple phrase or concept. It was clear, however, that the idea of the Griffith crack formed the basis of the attack in understanding fracture in most materials; it was specifically invoked in the discussion of fracture in metals, glass (of course!), paper, soil, mineral particles, wood and rocks. In his Tewksbury Lecture, Professor Cottrell developed a generalised treatment of a crack as a group of "crack dislocations"; the conditions for growth of this crack reduce to the Griffith criterion at low stresses. The treatment used ideas latent in previous lectures given by Professor Cottrell, particularly those at Swanscott¹ and at the Berkeley Conference on Nuclear Materials⁴. He discussed the way in which the crack dislocations give rise to a plastic strain field ahead of the crack ("cumulative crack") and how they might, under appropriate conditions, be converted into glide dislocations. This theory was developed rigorously for an elastic medium, leading to a description of brittle fracture, and then applied to ductile fracture in an elastic-plastic medium. Other types of fracture, described by Professor Cottrell as "discontinuous", were also mentioned: these included ones which start at internal particles or voids. The ductile bridges between voids play the part of the atomic bonds in the general theory.

Several papers emphasised the part of voids in the fracture of metals—under creep conditions, in ductile fracture and in fatigue. However, the evidence on how the voids form is ambiguous, because it is so difficult to observe the earliest stages of their formation; this is analogous to processes in biological evolution where a principle appears to apply which causes “the suppression of evolutionary peduncles”⁵. Grain size, impurity content, prior strain and so forth can affect the onset and course of fracture and much of the work reported for metals and ceramic materials was concerned with the sorting out of these factors; the possible mechanisms are reasonably understood, but the task is generally to decide how particular conditions predicate the course of fracture.

Although Griffith cracks have such wide popularity as a concept, the only substance in which they have been clearly demonstrated is glass, for which an ingenious ion exchange technique has been used to etch them up. It turns out that they are too narrow to be revealed by optical microscopy or by replication and that they form adventitiously by mechanical or chemical damage on a micro scale. Whether or not there are intrinsic flaws in carefully prepared glass is undecided but the evidence tends to discount them. In metals and ceramics the evidence is also against intrinsic Griffith cracks being present; the emphasis is on accounting for cracks on the basis of reactions between, or impurity effects on, dislocations. These ideas have been successfully applied to the machining of a metal (zinc), but with brittle materials like coal or polystyrene, experiments are still at the stage of analysing the stresses caused by the machining tool tip, so that mechanisms which are possibly appropriate can be isolated.

The fracture of large-scale engineering structures was discussed in connection with aircraft and bridges, where the problems of cumulative damage and crack propagation as a function of the particular design seem to dominate.

When fracture of natural materials was considered, the understanding was seen to be much less detailed; the emphasis was on overall mathematical models, which could permit the engineer to predict behaviour rather than allow the scientist to explain. This was so for rocks and minerals, but with some other materials, progress has been made by exploring the structure and its changes during deformation. In brown coal, for example, the strength is related to cross-linking between particles by aliphatic chains and the behaviour has been clarified by comparing with a previous model for clays. A somewhat similar effect was reported for paper, where the dominant strengthening is by hydrogen bonding; however, here the calculations appear to indicate some micro discontinuity, such as a Griffith crack, as the starting point of fracture. The fracture of wood has also been related to specific elements of its structure, namely the layers of the cell wall and, again, hydrogen bonding dominates.

Bonding between components is also of critical importance in another

complex material, concrete, whose fracture behaviour depends not only on the proportions and types of aggregate and cement used but on the nature of the bonding between aggregate and cement paste, which is modified by moisture, curing, etc.

Fracture, of course, always reduces to breaking bonds and the problems are firstly to recognise the critical bond and then to find a mechanism which will rupture the bond with a minimum expenditure of energy, consistent with the breaking stress. Those studying crystalline materials, particularly metals, have been able to go furthest in understanding fracture because of the diffuse nature of the atomic bonds and the enormously rapid expansion of knowledge of crystal defects in recent years; these features lead to mechanisms which involve the creation of the equivalent of a Griffith crack and obviate the necessity for postulating intrinsic flaws. One hopes that the same pattern of evolution in models for fracture will occur with the more complex materials and that the rate of progress will be increased by the interchange of ideas at Symposia such as this.

R. C. GIFKINS
(Victoria Branch)

REFERENCES

1. "Fracture" (Ed. Averbach et al.), 1959, London and New York (Chapman and Hall; John Wiley).
2. "Fracture of Solids" (Ed. Drucker and Gilman), 1963, London (Wiley).
3. A. N. Stroh, *Journal of Metals*, 1963, 15(1), 43.
4. "Properties of Reactor Materials and Effects of Radiation Damage" (Ed. Littler), 1962, London (Butterworth), p. 5.
5. P. T. de Chardin, "The Phenomenon of Man", Translated B. Wall, 1959, London (Collins).

M.Sc. Course on Continuum Mechanics

This course, which is of one year's duration, is to be held at the University College of Swansea in the coming academic year. It will include a broad range of topics that fall under the general heading of Continuum Mechanics and is intended to introduce students to the deformation and flow of liquids and solids with complicated rheological properties. Lectures will be given on:

- (1) General theory of deformation and flow (mathematical rheology), including the necessary tensor calculus.
- (2) Flow of viscous fluids.
- (3) Elasticity in solids, including large-strain (rubber-like) elasticity.
- (4) Plasticity theory.
- (5) Flow of elastico-viscous liquids.

Candidates for admission to the course should write to Professor J. G. Oldroyd, Department of Applied Mathematics, University College, Singleton Park, Swansea.

Help!

Dr. Scott Blair (National Institute for Research in Dairying, Shinfield, Reading) writes:

"Can any member give me a reference to, or lend me unpublished data in order that I may test an equation which should describe the relation between shear rate and stress for a shear-thickening system which gives, at least on extrapolation, a yield value? Truly dilatant systems or those which show shear blockage, i.e., a more or less complete failure to flow, would not be suitable. I have references to many papers describing shear-thickening but none seems to give any precise data in tabular form."

Future Meetings of the Society

Arrangements are now well advanced for the one-day meeting on "Rheology of Paints and Allied Products" to be held at the Paint Research Station, Teddington, on April 29th. Members were circulated with details several weeks ago.

The autumn meeting has now been arranged for September 28th to 30th, and will be held at the University of Exeter. Part of the meeting will be a Symposium on rheology in education and part will be devoted to rheogoniometry. Five papers have so far been offered on rheogoniometry; other papers are invited. The current interest in the expansion of all forms of higher education provides an opportunity for consolidating and improving the present status of rheology as a teaching subject. The Committee feel that the time is ripe for a full-scale discussion on the problems and opportunities involved. We hope to discuss the position of rheology in the teaching syllabus (does it get its fair share of attention?), the choice and presentation of courses in rheology (especially comprehensive courses at advanced level) and the design of teaching laboratory experiments. A large proportion of the time will be devoted to a discussion of the questions raised. We hope for a wide range of contributions from anyone interested in education. We plan to discuss whether the Society can, and should, take new steps to foster and encourage rheological teaching. Some papers are already being prepared but more will be welcome. We would like to hear especially from anyone who does not teach rheology but who subsequently employs the recipients of such teaching and who is willing to give a controversial (but not actually libellous) opinion of current rheological teaching. Anyone who is interested in contributing a paper or having something to say in discussion should get in touch with Dr. J. H. C. Vernon, 15 Long Deacon Road, Chingford, London, E.14.

Other Meetings

15th April, "Mixing and flow of non-Newtonian and heterogenous systems" at University College of Swansea (Institution of Chemical Engineers).

6th–8th April, “Microscopy of fibres and fibrous materials”, Manchester College of Science and Technology (Royal Microscopical Society).

8th–10th April, “Mechanics of inhomogeneous and anisotropic materials” (includes papers on fibre reinforced materials, anisotropy in elastic properties and rupture propagation) at M.C.S.T. (as above) organised by the Institute of Physics and the Physical Society.

6th–9th April, “Advances in materials” at M.C.S.T. (Institution of Chemical Engineers).

8th–10th April, Thermodynamics and Fluid Mechanics Group Convention, Cambridge, Institution of Mechanical Engineers.

12th–14th May, “Thermal loading and creep in structures and components”, London, Institution of Mechanical Engineers.

Finance : subscription increase

The financial position of the Society is giving the Executive Committee some concern. Our income has remained substantially constant over the years. Expenditure is rising faster than the increase in income derived from subscriptions from new members.

The rising cost of publications and administration have caused our cash reserves to drop. Looking ahead, it seems that these could be exhausted by 1965 or 1966. The present year's expected income and expenditure is set out below.

				<i>Total</i>	<i>Per Member</i>
Income	...	...	...	£370	£1 0 0
Expenditure:					
Publications	...	...	...	260	14 1
Administration	...	...	...	170	9 2
Meetings	...	...	...	30	1 7
Exploratory Committee Expenses				50	2 8
Total Expenditure		...	...	£510	£1 7 6
Deficit	...	...	...	£140	7 6

Three ways in which the Society's income could be increased—by increasing subscriptions, by making a profit out of meetings (this has not been the policy in the past) or by improving profit on sales of publications—are being considered in order to improve the Society's position. An increase in the subscription appears at present to be inevitable and it is probable that the A.G.M. will be asked to approve such a change. The amount of the increase which the Committee may recommend to the Society is likely to be £1. As members know, some interesting rethinking on rheological research and allied matters is going on. Clearly the Society must be in a position to follow such developments.

New Members

NAME AND ADDRESS

D. M. Bancroft,
Dept. of Mathematics,
Manchester College of Science and
Technology.

K. J. McKeown,
13 Pulford Road, Bebington,
Cheshire.

H. Archer,
Donald Macpherson and Co. Ltd.,
Bury, Lancs.

P. F. S. Cartwright,
344 Field End Road, Eastcote,
Ruislip, Middlesex.

Miss M. H. Davies,
Dept. of Applied Mathematics,
University College of Wales,
Aberystwyth.

D. P. Earp,
Protective Coatings Laboratory,
British Railway's Research Dept.,
Derby.

L. D. Eaton,
J. & E. Sturge Ltd., Birmingham 30.

S. R. Finn,
Blundell Spence & Co. Ltd., Hull.

K. R. Frater,
Dept. of Applied Mathematics,
University College of Swansea.

D. Harden,
149 Prince's Road, Dartford, Kent.

J. A. Hersey,
43 Weardale Avenue, Darenth,
Dartford, Kent.

F. J. Hiorns,
British Coal Utilisation Research Assn.,
Leatherhead, Surrey.

J. K. Jacques,
Albright and Wilson (Mfg.), Ltd.,
Oldbury, Birmingham.

W. Simpson,
207 Errwood Road, Manchester 19.

INTERESTS

Rotation viscometry. Birefringence.

Capillary and rotation viscometers.
Detergents and soaps.

Suspensions and rotation viscometry.

Pigment dispersions. Printing inks.

Theoretical rheology.

Paints.

Suspensions and rotation viscometry.

Polymers.

Theoretical rheology.

Suspensions.

Powders.

Powders. Abrasion and wear.

Paints and films.