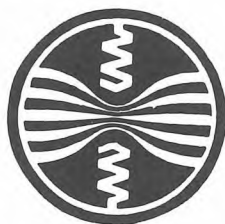


THE BRITISH SOCIETY OF RHEOLOGY

BULLETIN



1984, VOL. ²⁷~~26~~, NO. ¹~~4~~

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ISSN-0045-3145



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MR. H. SCHIMANSKI, Contraves Industrial Products, 50 Cromwell Avenue, Thame, Oxon., OX9 3TD.

EDITORIAL

"Rheology on TV" - at last our science has been given public recognition! Well at least we got onto Johnny Ball's childrens' programme called "Think of a Number". The programme usually concentrates on novel mathematical tricks, puzzles etc. but in one of the January editions it dealt with viscoelasticity. As we know viscoelastic effects are very visual and with correctly chosen materials, dramatic effects can be demonstrated (vide Ken Walters' film). Apart from a few understandable verbal errors Mr Ball had all his visuals correct!

We would like to hear from any reader who has captured any magic (rheological) moments in still shots - our pages are open to your efforts!

Ralph Oliver has asked us to publicise the fact that the forthcoming Birmingham meeting on General Rheology (see pps. 9-11) is a "good value for money" conference - all meals, two nights accommodation and 20 lectures - all for £63.25p.

Anyone wanting news about the latest group discount travel package to Acapulco - please contact John Benbow.

A handwritten signature in black ink, consisting of stylized initials 'JAB' followed by a period.

D.C.-H. Cheng
Warren Spring Laboratory,
Stevenage, Herts SG1 2BX

A paper of the above title was presented at the international symposium on The Role of Particle Interactions in Powder Mechanics, held at Eindhoven, the Netherlands, on 29-31 August 1983. The following is the text of the extended summary given at the meeting. The full proceedings of the conference will be published in Powder Technology, 1984, volume 37. The paper will be found on pp 255-273.

Let me begin by explaining what I mean by dense suspensions. The viscosity concentration curve of a suspension has the general shape shown in Fig. A. At infinite dilution, the viscosity η increases linearly with concentration C_V at a rate given by the intrinsic viscosity $[\eta]$. As C_V increases, η becomes dependent on C_V^2 , and then C_V^3 , etc - these are known as concentrated suspensions. Even then, we are only talking about 20 or 25% solids at the most. At these sort of concentrations, the agreement between theory and experiment, and between different research workers, (shown in Fig. B taken from Thomas (1965)) is pretty good, perhaps about $\pm 20\%$ spread, may be a little more. But as C_V is increased, through 40, 50, to 60 and 70% we begin to run into trouble. As the graph shows, the spread in experimental data becomes 5-fold or more.

The review of Rutgers in 1962 gives another view of the same situation. He cited some 280 references. The (η, C_V) equations, some theoretical and some derived from experimental results, are set out in a table that extends to $4\frac{1}{3}$ pages. They are divided into 10 categories, with further subdivisions. Rutgers plotted many graphs which show much wider spread than Fig. B. This disagreement between theories and experiments is an indication of the complexity of the rheological behaviour of suspensions.

There are other difficulties which I shall describe in a moment. These very high solids concentrations are the dense suspensions of my paper. As one might expect the situation is more complicated. There is no universal concentration which defines the limit of a dense suspension. It depends on particle size. Figure C gives a rough idea of the size-dependence. The limit also depends on particle size distribution, shear rate, viscometer geometry and dimensions, and other factors. For example, adding fines to a coarse suspension, increases the C_V limit. But there is no detailed information on these factors at present.

My interest in dense suspensions comes about in the contract research that my Laboratory carries out. Over the years we have been asked to test many high-solids materials, such as: graphite-in-oil paste, sand and gravel, mineral concentrates, mine tailings, colliery waste, spent wash from distillers, cement grouts for North Sea oil-platform legs and coal-in-water slurries. More recently, as part of a government-industry Cooperative Programme on Thick Liquids and Pastes (TLP), we have been studying the effect of particle size distribution on very high solids content PS sphere suspensions. We used glass spheres in dibutyl phthalate and PS beads in paraffin oil or in aqueous glycerol solution. When we carried out the viscometric measurements, we found very poor reproducibility - not just between different viscometers, but also between different sizes or dimensions of the same viscometer. Now, when a research student in an university is faced with such a situation, he is mindful that he needs to have to write a convincing thesis by the end of the year, so he moves onto lower concentrations where things are easier. But, at WSL we have taken money from our sponsors and are reluctant to give it back; so we persisted. By persisting and by testing a wide range of different materials, we found a definite pattern emerging. From this we have concluded that the rheological behaviour of dense suspensions is in a class of its own. We have described it as granuloviscous and my paper summarises our work and conclusions to date.

The viscometric difficulties we have in our work are already known in the literature. But because they are mostly given in the experimental sections (which no one really reads any way), their importance has not been realised.

From this point on, I shall concentrate on spherical particles (not necessarily monosized), but mostly so. They are neutrally buoyant and non-settling. The behaviour I shall describe has parallels in the real systems we have studied at WSL. So, although I shall confine my remarks to spheres, the phenomena I will discuss are generally valid to all suspensions. I should just emphasise that what I will discuss is the physical behaviour of suspensions. Chemical and colloidal properties are definitely excluded.

The first part of my paper describes some of the phenomena given in the literature. Five figures depict shear history effects:

Fig. 1 shows stress decay under constant shear rate testing in a rotation viscometer.

Fig. 2 rotation speed increase under constant stress testing.

Fig. 3 no stress recovery when interrupted shear is resumed in the same direction, but if shear is reversed, time-dependent behaviour is observed.

Fig. 4 hysteresis loop in an orifice viscometer.

Fig. 5 different results are obtained depending on whether the rotational speed is changed step-wise or continuously.

In Fig. 6A and 6B, different viscosity results are shown for different viscometers. At about 58% concentration the differences are about 10-fold. Other literature results show that, as concentration is increased beyond some high value in a rotational viscometer, the viscosity shows a sudden drop to almost zero. These and other results show very poor reproducibility and clearly indicate that particle migration and particle packing structure changes readily occur when a dense suspension is sheared.

The literature results are reflected in the observations from TLP work at WSL.

Fig. 8 shows changes in hysteresis loop on repeated cyclic shearing

in a coaxial cylinder viscometer.

Fig. 9 the size of hysteresis loop increases with C_V .

Fig. 10 the amount of shift of between repeated loops increases with C_V .

Fig. 12 shows that measured viscosity increases as viscometer gap is increased up to some critical value, and then decreases as the gap is increased further. The former may be explained in terms of wall slippage, but the latter is not yet explained.

Fig. 13 viscosity increases with C_V up to a maximum, and then decreased as C_V is increased further in a coaxial cylinder viscometer.

Fig. 14 different results for different viscometers.

Fig. 15 blockages in a tube viscometer increasing as C_V increases.

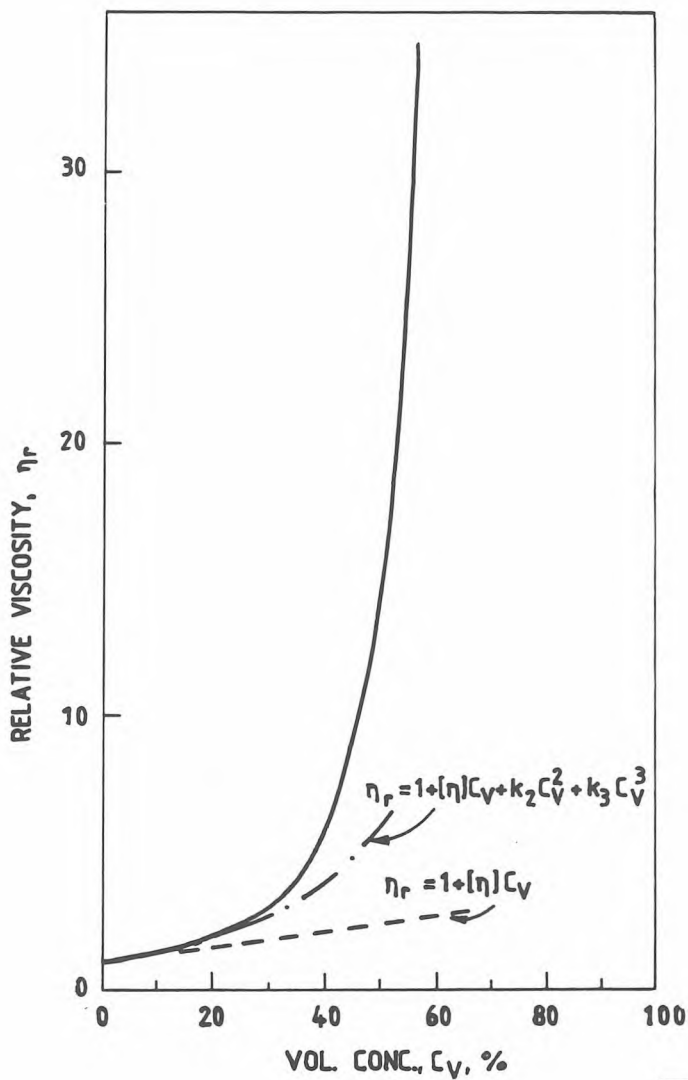
Other WSL results show fluctuating readings at constant rotational speed, unusually large end effects in coaxial cylinder and tube viscometers, and complex dependence of wall-slip velocity in tubes on tube diameter. All the results show poor reproducibility and indicate the existence of particle migration and particle packing structure changes during shear.

All these literature and WSL results point to the conclusion that dense suspensions are inherently two-phase systems and cannot be treated as homogeneous, even with neutrally buoyant particles. During flow, phase separation takes place (described variously as particle migration, or changes in local concentration or particle packing density or structure) and this governs the overall behaviour of the suspension. The details of the microrheological behaviour depends on the exact flow situation involved, in a complicated way, such that there is no unique viscosity (Newtonian or non-Newtonian). It (that is the viscosity) depends on the geometry and dimensions of the viscometer used.

In addition, because we are dealing with a small number of particles

(some thousands or maybe several million, but certainly much less than the Avogadro number 6×10^{23}), reproducibility of solids content and particle size distribution in test samples is significantly poor. Furthermore the experimenter has no control of the particle packing structure from run to run. All this means that the reproducibility in a prescribed viscometer can be expected to be very poor. Thus the dense suspension rheology is characterised not by a unique viscosity or flow curve, but by a viscosity distribution or a "flow band". In measuring viscosity, we have to determine not just the mean value, but the standard deviation has also to be determined to within acceptable uncertainties.

In concluding my paper, I also discuss the implications of these conclusions for the testing of materials in the research laboratory and for the study of their behaviour in handling and processing equipment. The reader is referred to the full paper for details.



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**FIG.A IDEALISED VISCOSITY-CONCENTRATION RELATIONSHIP
FOR A SUSPENSION OF SPHERES**

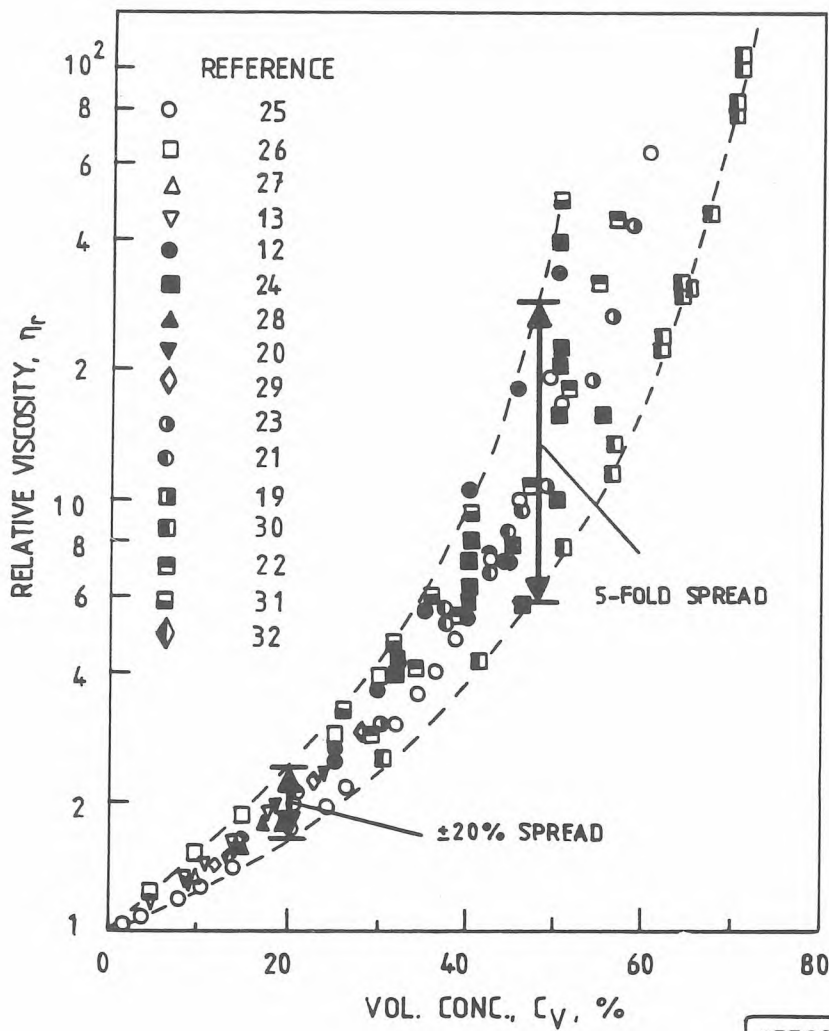
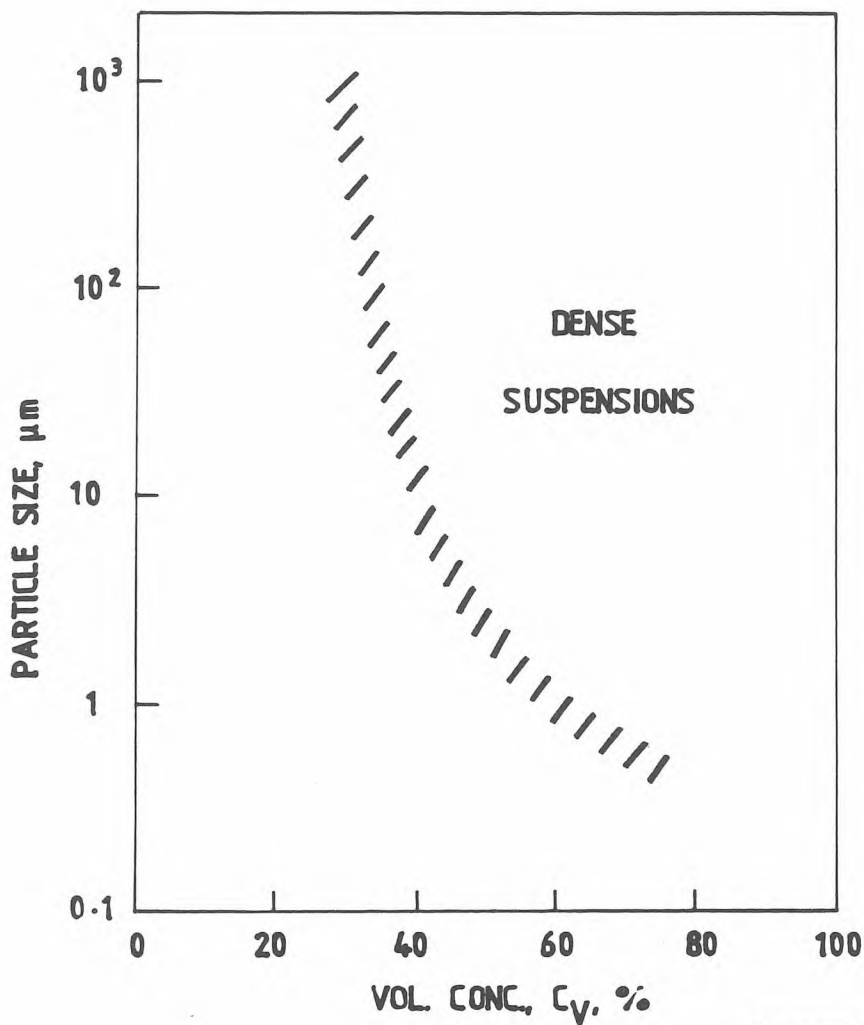


FIG.B EXPERIMENTAL VISCOSITY-CONCENTRATION RELATIONSHIP
TAKEN FROM THOMAS (1965)



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FIG.C DEPENDENCE OF DENSE SUSPENSION ON
PARTICLE SIZE

"GENERAL RHEOLOGY" "GENERAL RHEOLOGY"

A Conference to be held at
Ridge Hall,
Church Road, Edgbaston,
(Vale Conference Centre)
Near Birmingham University,
England.

11th – 13th April, 1984.

A broad spectrum of papers has now been received for this meeting, and it is expected that the abstracts will be published in Rheology Abstracts, Issue No 1, 1984. The Society does not, in general, publish their Conferences in a more complete form.

The meeting will take place in the Vale Conference Centre, which is in an attractive position alongside an artificial lake. Ridge Hall is set high on the east side of the lake and lecture room, accommodation, eating and bar facilities are in this hall under one roof.

A booking has been made to take a party round the Austin Metro production line at Longbridge. This is one of the most automated lines in Europe.

Application forms to attend the Conference are available from:

Dr D R Oliver
Department of Chemical Engineering
The University of Birmingham
PO Box 363
Edgbaston
Birmingham
B15 2TT

Wednesday, 11th April

- Conference Assemblies
- 12.30 Lunch
- 2.15 T. H. HAMMOND
"Rheological studies of Bakers Yeast in Aqueous Suspension"
- 2.40 T. E. R. JONES, J. M. DAVIES, and
P. R. RUTTER
"Role of Rheology in predicting the sedimentation stability of coal/oil dispersions."
- 3.05 R. BUSCALL, I. MCGOWAN, R. F. STEWART
and D. SUTTON
"Consolidation of flocculated dispersions in centrifugal fields—a Rheological approach."
- 3.30 Tea
- 3.55 T. A. STRIVENS
"The viscoelastic properties of concentrated non-aqueous dispersions—effects of concentration, medium and temperature."
- 4.20 A. W. NIENOW, K. V. ALLSFORD
"Gas-Liquid mixing in constant viscosity and shear thinning viscoelastic fluids."
- 4.55 J. J. BENBOW
"Speculation on frictional effects during polymer melt extrusion."
- 7.00 DINNER

Thursday, 12th April

- 9.15 R. J. J. JONGSCHAAP
"A new derivation of the expressions of the average stress tensor in polymeric and disperse systems."
- 9.40 M. R. MACKLEY and I. P. T. MOORE
"The measurement and prediction of stress buildup and relaxation for polyethylene flowing in a well-defined duct."
- 10.05 J. F. HUTTON
"Effects of temperature, pressure and shear rate on motor oil viscosity—a normalisation procedure."
- 10.30 Coffee
- 10.50 F. S. BAKER, R. E. CARTER, R. GLEDHILL,
M. JONES and G. PRIVETT
"The Rheology of nitrocellulose pastes."
- 11.15 R. E. CARTER and R. C. WARREN
"Extrusion effects in double-base propellant doughs."
- 12.00 Lunch

Thursday, 12th April

- 1.30 Free time and visit to University.
- 3.45 Tea
- 4.10 D. A. BROOKS
"Electro-rheological fluids."
- 4.35 D. R. OLIVER and A. W. NIENOW
"The mixing of Boger fluids."
- 5.00 H. A. BARNES and G. P. ROBERTS
"The Sisko model revisited."
- 7.30 CONFERENCE DINNER

Friday, 13th April

- 9.15 D. BOGER
Annual award lecture.
- 10.15 W. M. JONES, T. S. VIRDI and P. R. WILLIAMS
"The elongation of radial filaments of a Boger fluid on a rotating drum."
- 10.40 Coffee
- 11.00 R. BUSCALL, D. J. BYE and I. S. MILES
"Elongational flow of poly(ethylene oxide) solution."
- 11.25 D. R. OLIVER
"Rapid conical flows of viscoelastic solutions."
- 11.50 I. P. T. MOORE
"The application of photon correlation velocimetry to velocity profile measurement in ducts."
- 12.30 Lunch
- 2.00 J. M. DAVIES and T. E. R. JONES
"Automatic data logging system for a Weissenberg Rheogoniometer"
- 2.25 D. C. H. CHENG and C. A. MOULES
"Correlation for gap-setting error in the cone and plate viscometer."
- 2.50 J. F. HUTTON — President's address.
"Reflections on a career in Rheology."
- 3.15 End of Conference.

CONFERENCE FEE

- A. Including all meals, two nights accommodation
£55.00 + £8.25 (V.A.T.) = £63.25
- B. As in A, but excluding Conference Dinner
£45.00 + £6.75 (V.A.T.) = £51.75
- C. As in A, but for one night only
£40.00 + £6.00 (V.A.T.) = £46.00

N.B. After Friday March 9th, 1984, a *surcharge* of £5.00 is payable

THE BRITISH SOCIETY OF RHEOLOGY

NOTICE OF CONFERENCE

TOPIC "RHEOLOGY OF LUBRICATION & OTHER INDUSTRIAL PROCESSES"

VENUE Physics Department, University College of Wales, Aberystwyth

TIME 11th - 13th September, 1984

PROVISIONAL SCHEDULE

Tuesday, 11th September, 1984

1.00 p.m. Lunch at Penybryn Hall

2.00 - 5.30 p.m. "Lubricants and Lubrication"

Professor D Tabor (Cambridge University) on
Molecular Models in Lubricant Viscosity.

Dr D M Heyes (Royal Holloway College) on
Molecular Mechanisms of Shear Flow.

Dr J H R Clarke (UMIST) on
Molecular Dynamics Calculations.

Dr G C Maitland (Imperial College) on
Effects of Chain Flexibility and Inter-
molecular Forces on Rheological Properties.

Dr D R Oliver (Birmingham University) on
Load Enhancement Effects by Polymer-thickened Oils.

Dr B Briscoe (Imperial College) on
Friction of Organic Polymer Films.

6.00 p.m. Annual General Meeting of BSR.

Wednesday, 12th September, 1984

9.00 - 12.30 p.m.) "Industrial Rheology Workshop" including
3.00 - 5.00 p.m.)

Mr J F Hutton (Shell Research) on lubricants.

Dr H A Barnes (Unilever) on detergents.

Mr F N Cogswell (ICI) on molten plastics.

Dr J R A Pearson (Schlumberger) on Systems Engineering & Industrial Rheology.

Dr J J Benbow (Birmingham University) on Methods of measuring paste Rheology.

Mr T C Davenport (BP) on oil recovery.

2.00 - 3.00 p.m. Gold Medal Address:

PROFESSOR K WALTERS

7.00 p.m. Reception and Conference Dinner

Thursday, 13th September, 1984

For additional contributions on friction and lubrication.

For visits to the Rheology Laboratory : Dept. of Applied Mathematics.

Call for Papers:

Papers are still required for the lubricants and lubrication rheology section,
please contact the President.

NOTICE



SOLUTIONS TO STICKY PROBLEMS

Problems in the handling of wet and sticky granular solids at 26 ICI plants and at plants at other companies have been the subject of a recent survey by Warren Spring Laboratory (WSL). This survey indicates that there are a large number of problems widespread across many industries, including the process, construction and agricultural industries. Such problems include:

- . blockage of pipelines and transfer chutes;
- . discharge from hoppers and drums;
- . build-up and blockage in screw and drag-link conveyors;
- . phase separation and caking on storage;
- . feeding and metering of pastes;
- . poor performance of paste extruders.

To find solutions to these problems, WSL is starting a research programme geared to the development of design and selection procedures for wet solids conveying, storage and processing equipment. The work will be a cooperative venture between Industry and Government with joint funding, and will begin in July, 1984. This programme is yet another organised by WSL to assist the process industries and their suppliers.

An open meeting on Thursday, 12 April 1984, for all companies interested in the proposed project will be held at WSL.

Warren Spring Laboratory

Department of Trade and Industry, PO Box 20, Gunnels Wood Road, Stevenage, Herts. SG1 2BX.
Telephone: Stevenage (0438) 313388, Telex: 82250. Contact Dr N I Heywood.

2-5 April Sheffield, England. Fundamentals of Deformation and Fracture.
J. Eshelby in memoriam (IUTAM/ICP/ICM)

Contact Professor K. J. Miller, Department of Mechanical Engineering, University of Sheffield, Mappin St., Sheffield. S1 3JD, U.K.

10-13 April Bucharest, Romania. The mechanics of oil recovery (Euromech 178)

Contact Dr. H. I. Ene, INCREST, Department of Mathematics, Bd Pacii 200, 79622 Bucharest, Romania.

11-13 April Birmingham, England. General Rheology (B.S.R.)

Contact Dr. D. R. Oliver, Department of Chemical Engineering, University of Birmingham, P.O. Box 363, Birmingham B15 2TT, U.K.

?-? May Detmold, Germany. Rheology of Foodstuffs (DRG)

Contact Professor K. Kirschke, Deutsche Rheologische Gesellschaft e.V., Unter den Eichen 87, D1000 Berlin 45, B.R.D.

25-27 June Essen, Germany. Influence of polymer additives on Velocity and temperature fields (IUTAM)

Contact Professor B. Gampert, Univ. Essen Gesamthochschule, Fachbereich 12, Maschine technik, Postfach 103764 D-4300 Essen, BRD.

19-25 August Lyngby, Denmark. XVI International Congress of Theoretical and Applied Mechanics

Contact Dr. N. Olhoff, ICTAM, Technical Univ. of Denmark, Building 404, DK-2800 Lyngby, Denmark.

29-31 August Brussels, Belgium. Mechanical characterisation of load-bearing fibre composite laminates (Euromech 182)

Contact Professor A. H. Cardon, Vrije Universiteit Brussel, Faculty of Applied Sciences, Pleinlaan 2, 1050 Brussels, Belgium.

3-7 September Prague, Czechoslovakia. 8th CHISA Congress with European Symposia on Stress and Strain Behaviour of Particulate Solids and on Mixing of Non-Newtonian Industrially Important Fluids

Contact 8th Congress CHISA '84, P.O. Box 857, 11121 Praha 1, Czechoslovakia.

4-8 September Moscow, USSR. International Rubber Conference

Contact Professor V. A. Berestnev, General Secretary, "Rubber 84" Organising Committee, Krasnobogatyrskaya Street 42, Moscow 107258, USSR.

- 12-14 September Nancy, France. Rheology of biological fluids (Euromech 186)
- Contact Professor M. Lucius, Institut National Polytechnique de Lorraine, B.P. 3308, Porte de la Craffe, 54014 -Nancy Cedex, France.
- 16-23 September Varna, Bulgaria. 10th International Conference on Nonlinear Oscillation
- Contact Academician G. Brankov, Institute of Mechanics and Biomechanics, "Acad. G. Bonchev" Str. B18, 1113 Sofia, Bulgaria.
- 17-21 September Prague, Czechoslovakia. Optical Methods in the Dynamics of Fluids and Solids (IUTAM)
- Contact Professor M. Pichal, Institute of Thermomechanics, Czechoslovak Academy of Sciences, Puskinovo n.9, CS 160 00 Praha 6, Czechoslovakia.
- 24-27 September Villetaneuse, France. Plasticity of crystalline media (Euromech 183)
- Contact Dr. A. Zaoui, Laboratoire P.M.T.M., C.N.R.S. Univ. Paris-Nord, Avenue J.B. Clement, 9340 Villetaneuse, France.
- ?-? September Granada, Spain. Annual meeting (Spanish Rheology Group)
- Contact Dr. J.V. Aleman, Instituto de Plasticos y Caucho Juan de la Cierva 3, Madrid 6, Spain.
- 8-13 October Acapulco, Mexico. IX International Congress on Rheology
- Contact Professor B. Mena, Instituto de Incestigaciones en Materiales, Apdo. Post. 70-360, Ciudad Universitaria, Coyoacan 04510, Mexico D.F., Mexico.
- ? Sept/Oct London, England. Friction and Lubrication (BSR)
- Preliminary announcement - one-day meeting.
- Contact Dr. J. J. Benbow, Department of Chemical Engineering, University of Birmingham, P.O. Box 363, Birmingham B15 2TT, U.K.
- 12-15 December Cambridge, England. The physics of dispersion of small particles (Euromech 191)
- Contact Dr. E. J. Hinch, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Silver Street, Cambridge. CB3 9EW, U.K.

MEMBERSHIP NEWS

The following applications for Membership were approved at the Council meeting on December 9th 1983

Dr Philippe BAUDEAU	Docteur Ingenieur
Institut Universitaire de Technologie	
Departement Genie Civil	fetsa H
Strasbourg III	
Route du Rhin 67400	
Illkirch FRANCE	

Miss Vinabon BODALIA	BSc
Department of Mathematics & Computing	
Polytechnic of Wales	feta DFGIJLN
Pontypridd	
Glamorgan CF37 1DL	

Mr Kevin Ronald BOLT	HNC
Johnson Wax	
Milton Park, Stroude Road	petsa DFGJ
Egham, Surrey	

Mr Douglas Alan BROOKS	BSc Hons, MSc
Laser Engineering (Dev) Ltd	
No 4 Charlotte Rd	fetsa G
London EC2	

Dr A.K CHESTERS	MA, PhD
Unilever Research Laboratory	
Olivier van Noort Laan 120	fetsa DFGHL
Vlaardingen	
THE NETHERLANDS	

Mrs Barbara DEW	BSc
British Gas	
Midlands Research Station	fea G
5 Wharf Lane	
Solihull, West Midlands	

Dr Timothy Peter ELSON	BSc, PhD
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University College London	peta DFGL
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pea BCD

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Cambridge

Doctorandus, PhD
peta DFG

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National Tsing Hua University
Hsinchu
TAIWAN

BS, MS, PhD
fetsa BCDG

Dr Herman KILLESREITER
Institut für Erdölforschung
Walter-Nernst-Strasse 7
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WEST GERMANY

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fesa DFJ

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British Ceramic Research Association
Queen's Road
Penkhull, Stoke-on-Trent, ST4 7LQ

BSc (Hons)
feta CDFGHK

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PO Box 1, Romford
Essex

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petsa ABCDEFGHIJKLMN

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Sussex

fea ABCDEFGHIJKLMN

Mr Hugh Adrian POTTS
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petsa DFGJ

Mr Richard SELLMAN
Evode Ltd
Common Road
Stafford

Grad RSC

peta DGK

Dr James F. STEFFE
Dept of Agricultural Engineering
Michigan State University
E. Lansing
MI 48824
USA

BA, BSc, MSc, PhD, PE

fetsa FGHL

Mr Harold Devashanth THURAIRATNAM
University College London
Civil & Municipal Eng. Dept
Gower Street
London WC1E 6BT

BSc (Eng)

peta G

Dr Christopher Norman TYSON
Devro Ltd
Moodiesburn
Glasgow G69 0JE

BSc, PhD, M.Inst.F.

feta BDGL

HONORARY MEMBERS

Mr M.M Cross, Mr T.C Davenport and Dr W.M Jones were elected to Honorary Membership at the September Council Meeting.

RESIGNATIONS

Mr A Chakrabarti. School of Mathematical Sciences, Plymouth Polytechnic

Now a member of the Australian Society of Rheology

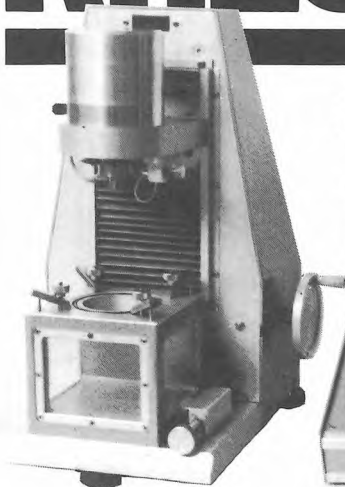
Mr D Sturman. BIP Chemicals Ltd, Oldbury, Warley, West Midlands
Joined in 1965

CAN YOU HELP?

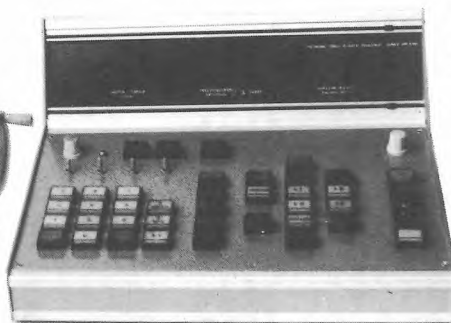
We have a number of Members on our records whose addresses are now out of date and with whom as a result we have lost contact. The Membership Secretary would be very grateful if anyone could put him back in contact with any of the following Members. The affiliations given were the last known.

Addis R.P	Camberley, Surrey
Coomber P.J	Instron ltd, High Wycombe
Gillham A.J	Tarporley, Cheshire
Graham A	Farnham, Surrey
Hiorns F.J	Effingham, Surrey
Laidlaw T.G	Rank Xerox, Welwyn Garden City
Lewis G.A	Brunel University
Lockwood B	Biospecialities, Reading
Meadows P	Maidstone, Kent
Meyer M.C	Nottinghamshire
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