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TECHNICAL ARTICLES & ADVERTISING
DEBUT IN RHEOLOGY BULLETIN

This issue of Rheology Bulletin contains an article by Professor I. Manas-Zloczower entitled, “Analysis of Mixing in Polymer Processing Equipment.” Such articles will now be a regular feature of the Bulletin. Author guidelines may be found on page 8. Commercial advertising is also introduced with this issue. Contact the Editor if you wish to place an advertisement.
The Hyatt on Capital Square is a 22 story 400 room luxury hotel in downtown Columbus directly across from the historic State Capital Building which was completed in 1861 in Greek Revival architecture style. It is the eighth oldest working Statehouse in the nation. Abraham Lincoln’s body was laid in state in the rotunda of the Capital in 1865 on the way home to Illinois. The Capital has recently been restored to its original grandeur at a cost of $112 million.

The hotel is adjacent to the Ohio Theater and the Columbus City Center, a three story upscale mall with three major department stores and 121 specialty shops. The Hyatt on Capital Square has an award-winning restaurant, two bar lounges, and the 6,000 square foot Governor’s Ballroom. Facilities include a Penthouse Fitness Center with exercise and workout equipment, a sauna, and whirlpool.

Port Columbus International Airport is fifteen minutes away and is served by most major airlines. Within blocks of the hotel are major corporate offices, the Columbus Museum of Art, and the Center of Science and Technology. The hotel provides complimentary downtown shuttle service. Weather in Columbus in October is generally pleasant with temperatures ranging from 45 to 65 F, but bring a raincoat just in case.

Registration and housing forms, and other information on the Columbus meeting will be included in the July Bulletin.

2. MELT FLOW INSTABILITIES AND WALL SLIP:

Shi-Qing Wang
Department of Macromolecular Science
Room 342, Kent Hale Smith Building
Case Western Reserve University
Cleveland, OH 44106
(216) 368-6374; Fax: (216) 368-4202
e-mail: sxwl3@po.cwru.edu

John M. Dealy
Faculty of Engineering, McGill University
817 Sherbrooke Street West
Montreal (Quebec) CANADA H3A 2A7
(514) 398-7251; Fax: (514) 398-7379
e-mail: JOHN@ENG1.LAN.McGill.CA

3. NOVEL POLYMER SYSTEMS:

Michael Mackay
Department of Chemical Engineering
The University of Queensland
St. Lucia, Brisbane
QLD 4072, AUSTRALIA
61 7 3365-4171 (or 3708); Fax: 61 7 3365-4199
e-mail: m.mackay@cheque.uq.oz.au

Anthony J. McHugh
Department of Chemical Engineering
University of Illinois
Urbana, IL 61801
(217) 333-1178; Fax: (217) 333-5052
e-mail: mchugh@aries.scs.uiuc.edu

4. RHEOLOGY AND MIXING:

Deepak Doraiswamy
DuPont Advanced Fiber Systems
5401 Jefferson Davis Hwy.
Richmond, VA 23234
(804) 383-3154; Fax: (804) 383-3519
e-mail: doraisd@spoc.dnet.dupont.com

Ica Manas-Zloczower
Department of Macromolecular Science
Case Western Reserve University
Cleveland, OH 44106
(216) 368-3596; Fax: (216) 368-4202
e-mail: ixm@po.cwru.edu
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Jan van Egmond
Department of Chemical Engineering
University of Massachusetts
Amherst, MA 01003-3310
(413) 545-0593; Fax: (413) 545-1647
e-mail: vanegmon@ecs.umass.edu

6. HETEROGENEOUS SYSTEMS:

Joe Goddard
Department of AMES
University of California – San Diego
La Jolla, CA 92037-0242
(619) 534-4308; Fax: (619) 534-4543
e-mail: jgoddard@ucsd.edu

Andrew M. Kraynik
Department 9112, MS0834
Sandia National Labs
Albuquerque, NM 87185-0834
(505) 844-9696; Fax: (505) 844-8251
e-mail: amkrayn@engsci.sandia.gov

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Davide A. Hill
Department of Chemical Engineering
University of Notre Dame
Notre Dame, IN 46556
(219) 631-8487; Fax: (219) 631-8366
e-mail: Davide.A.Hill.1@nd.edu

Lynn Walker
Department of Chemical Engineering
Carnegie-Mellon University
Pittsburgh, PA 15213-3890
(412) 268-3020; Fax: (412) 268-7139
e-mail: lwalker+@andrew.cmu.edu

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University Park, PA 16802-5007
(814) 865-3457; Fax: (814) 865-2917
e-mail: RH@pflmsc.psu.edu

Michael Rubinstein
Department of Chemistry, CB# 3290
Venable and Kenan Laboratories
University of North Carolina
Chapel Hill, NC 27599
(919) 962-3544; Fax: (919) 962-2388
e-mail: mrubinstein@unc.edu

9. SUSPENSIONS

Ronald Phillips
Dept. of Chemical Engineering & Materials Science
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Davis, CA 95616
(916) 752-2893; Fax: (916) 752-1031
e-mail: phillips@stokes.engr.ucdavis.edu

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Dept. of Food Science and Technology
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e-mail: cfshoemaker@ucdavis.edu

11. RHEOLOGY OF SOLIDS:

Gregory B. McKenna
NIST Polymers Division
A-2089 Bldg 224
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e-mail: greg@micf.nist.gov

Robert Shay
GE Corporate R & D
Engineering Mechanics Laboratory
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1 Research Circle
Schenectady, NY 12309
(518) 387-7006; Fax: (518) 387-7006
e-mail: shy@excrge.crd.ge.com

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GE Corporate R & D
Engineering Mechanics Laboratory
Bldg. K1. Room 3A22
1 Research Circle
Niskayuna, NY 12309
(518) 387-7484; Fax: (518) 387-7006
e-mail: hasan@crd.ge.com

12. GENERAL SESSION:

Robert L. Powell
Dept. of Chemical Engineering & Materials Science
University of California
Davis, CA 95616
(916) 752-8779; Fax: (916) 752-1031
e-mail: rlpowell@ucdavis.edu

POSTER SESSION: Prospective presenters are encouraged to use the Web-based submission procedure exclusively. Papers should be submitted by September 5, 1997 to:

Lewis E. Wedgewood
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MINUTES OF THE EXECUTIVE COMMITTEE MEETING
August 18, 1996

The meeting was called to order at 9:00 a.m. in the Quebec Hilton, Quebec City, Quebec, Canada. Executive Committee Members in attendance included: Kurt Wissbrun, Ron Larson, Morton Denn, Bob Armstrong, Gerry Fuller, Jeff Giacomin, and Andy Kraynik. Invited guests included: Monty Shaw, Rakesh Gupta, Jack Zakin, Peter Clark, and Janis Bennett.

The minutes of the March 24, 1996 Executive Committee Meeting, which appeared in the July 1996 Rheology Bulletin, were approved as read.

The committee considered an objection, raised by Joe Goddard, to advertising appearing in the Journal of Rheology and decided to continue the current policy.

Monty Shaw, Associate Editor for Finance, provided a Financial Report for the Journal of Rheology. We currently have 471 institutional subscriptions -- dropping below 500 for the first time in recent years. This decline is consistent with the trend established over the last several years. Morton Denn indicated that editorial activities for the Journal are running smoothly.

Kurt Wissbrun reported on the cost of archiving the Journal of Rheology on CD-ROM: $50,000 to produce the first 500 copies and $2.25 for each additional copy of back issues. The disk would be searchable by articles, authors, and abstracts. Kurt also read a report on the financial position of the Society, which was submitted by the Treasurer, Ed Collins.

Rakesh Gupta, Editor of the Rheology Bulletin, indicated interest in forming an ad hoc committee on publishing short articles in the Bulletin. The relation between our WWW page and the Bulletin was also discussed.

Ron Larson led discussion on future meetings of the Society. Maintaining industrial participation at meetings is a concern. Ron read a report provided by Bill VanArsdale on local arrangements for the meeting in Galveston, Texas, February 16-20, 1997. Jack Zakin reported on local arrangements for the regular annual meeting in Columbus, Ohio, October 19-23, 1997. Gerry Fuller discussed plans for a meeting in Monterey, California, October 4-8, 1998. Jeff Giacomin talked about the annual meeting in Madison, Wisconsin, October 17-21, 1999.

The Committee voted to increase to $1500 our contribution to the Physics Olympiad, which is sponsored by AIP. Peter Clark discussed activities of the Education Committee, which he chairs. Jeff Giacomin provided his regular update on healthy Society membership. Kurt Wissbrun appointed an ad hoc committee to consider revising the Society Constitution; the committee includes: Art Metzner, Faith Morrison, and Jeff Giacomin. Janis Bennett provided an update on AIP activities of concern to the Society.

The meeting was adjourned at 2:00 p.m.

NOMINATIONS INVITED

The Nominating Committee is soliciting nominations for all elected positions within the Society, but particularly for the member-at-large positions. Recommendations should be sent before March 15, 1997 to any committee member. Suggestions may be faxed to Bob Mendelson, the committee chair, at (281) 834-1793.
ANALYSIS OF MIXING IN POLYMER PROCESSING EQUIPMENT

Ica Manas-Zloczower
Department of Macromolecular Science
Case Western Reserve University
Cleveland, OH 44106

Mixing is a key step in almost every polymer processing operation, affecting material properties, processability and cost. Polymers are blended with other polymers to combine their properties and sometimes to even synergistically increase their physical characteristics. Various additives and reinforcing agents are mixed with polymers to improve mechanical performance and impart specific properties to the mixture. The need for developing new materials with improved properties seems to rely nowadays more on blending and compounding than on the synthesis of chemically new polymers. Therefore the importance of a more fundamental understanding of the mixing process and its dynamics is clearly undeniable.

Modeling the mixing process in real mixing equipment through flow simulations is not an easy task. Major obstacles include, but are not limited to, the very complex geometry of the mixing equipment, the time dependent flow boundaries and the difficulties involved in selecting the appropriate "indexes" to quantify the mixing process. Yet modeling offers a means for understanding, designing and controlling the mixing process.

Key to a fundamental understanding of the mixing process and its optimization is the clear distinction between "dispersive" and "non dispersive" mixing mechanisms and identification of the important process characteristics enhancing realization of these mechanisms. In a multiphase system, dispersive mixing involves the reduction in size of a cohesive minor component such as clusters of solid particles or droplets of a liquid. Distributive mixing is the process of spreading the minor component throughout the matrix in order to obtain a good spatial distribution. In any mixing device, these two mechanisms may occur simultaneously or stepwise. Figure 1 depicts schematically these two mixing mechanisms.

The conditions under which dispersive mixing occurs are determined by the balance between the cohesive forces holding agglomerates or droplets together and the disruptive hydrodynamic forces. Quantitative studies of droplet breakup in simple shear and pure elongational flows [2-7] have shown that elongational flows are more effective than simple shear flows, especially in the case of high viscosity ratios and low interfacial tensions. Also, the magnitude of the applied stresses plays a decisive role in determining droplet size distribution. These studies have been supported by the experimental results reported by Powell and Mason [8] and the theoretical calculations of Manas-Zloczower and Feke [9] who point out that elongational flows enhance the process of agglomerate dispersion by comparison with simple shear flows. In mixing equipment, the complex flow geometry generates field patterns which represent a superposition of flows ranging from pure rotation to pure elongation. Thus, assessing dispersive mixing efficiency in mixing equipment in terms of elongational flow components as well as stress distributions seems appropriate.

Distributions of stress and elongational flow give only a global perspective on mixing efficiency in various types of equipment. A more accurate prediction of mixing efficiency would involve tracking the elements of the minor phase (droplets or agglomerates) during their entire residence time in the equipment and following the dynamics of their breakup / coalescence. Such an approach, if achievable, would be prohibitively expensive in terms of computing time and memory. However, the global approach of characterizing mixing efficiency provides one a means to discriminate between various designs and processing conditions for mixing equipment.

Figure 1  Schematic illustration of dispersive and distributive mixing mechanisms.
Besides its intrinsic limitations, this global approach poses additional problems. As mentioned previously, in most of the existing mixing equipment we face the problem of time-dependent flow boundaries. Take as an example the kneading discs in a corotating twin screw extruder. As the discs rotate, the overall geometry of the flow field changes. A simplified approach to solve for this problem is to select a number of sequential geometries / snapshots for a complete mixing cycle and solve the flow problem in each geometry [10,11]. For polymer processing operations involving laminar flow of highly viscous materials, the overall effect caused by a changing geometry can be analyzed from the results obtained separately in selected sequential geometries. One can then proceed by solving the field equations for each sequential geometry. Shear stress distributions can be obtained for all sequential geometries and subsequently analyzed.

Another important characteristic of the flow field, relevant for dispersive mixing efficiency is the flow "strength". Steady flows can be classified according to the frame invariant concept of flow strength [12,13] in terms of the flow strength parameter, \( S_f \), is defined as:

\[
S_f = 2 \left( \frac{trD^2}{trD^2} \right)^2
\]

where \( D \) is the rate of deformation tensor and \( \dot{D} \) is the Jaumann time derivative of \( D \) (i.e. the time derivative of \( D \) with respect to a frame that rotates with the angular velocity of the fluid element). The flow strength parameter ranges from zero for pure rotational flow to infinity for pure elongational flow; its value is unity for simple shear flow. Determining the numerical value of this parameter requires second derivatives of the velocities. When using the finite element method in flow simulations, high density mesh designs are required in order to minimize the numerical error. This requirement is sometimes impeded by computational limitations, especially when considering processing equipment of very complex geometries.

A different way to quantify the flow strength is by considering the relative magnitude of the rate of deformation and vorticity tensors. A parameter \( \lambda \) can be defined as:

\[
\lambda = \frac{|D|}{|D| + |\omega|}
\]

where \(|D|\) and \(|\omega|\) are the magnitudes of the rate of strain and vorticity tensors respectively. The above parameter assumes values between 0 for pure rotation and 1 for pure elongation, with a value of 0.5 for simple shear. Although not frame invariant, it can be used as a first approximation to discriminate between various equipment designs and processing conditions in terms of their dispersive mixing efficiency [14,15].

Aside from breaking clusters of fine particles or droplets of an immiscible fluid, the aim of any mixing operation is to reduce system nonuniformity. This is accomplished by a repeated rearrangement of the minor component into the major one. In this case, the mechanism of mixing is distributive.

In order to study distributive mixing, one has to track the position of the minor component elements (fluid elements or solid particles) at each instant of the process. This is not an easy task and is usually achieved only by introducing simplifying assumptions. In most cases the minor component elements are assumed to be massless points, such that their presence does not affect the flow field of the otherwise pure matrix. Furthermore, interactions among particles, such as Van der Waals attraction force, friction, and droplet coalescence are ignored. With these simplifications, the location of minor component elements can be found by tracking their motion in the mixing region, provided that their initial position is known. Figure 2 is an illustration of one particle trajectory in a single screw extruder. Due to computational limitations, usually only several thousand particles can be tracked simultaneously during their motion in the equipment.

Figure 2  Particle trajectory in a single screw extruder.
In order to facilitate a quantitative analysis of the distributive mixing process, one needs to develop a framework which can provide the means to differentiate among various equipment designs or processing conditions. One index, frequently used for the characterization of distributive mixing efficiency, is the length stretch (distribution and average value) \[16\]. The length stretch \( l \) is defined as the ratio of the distance between two particles at any time \( t \) to the initial value of the distance between the same particles \[17\]:

\[
I = \frac{|X|}{|X_0|} \quad (3)
\]

where \( |X_0| \) is the magnitude of the vector defining the initial locations of two neighboring and distinct particles and \(|X|\) defines their locations at time \( t \). For a system with \( N \) particles, the length stretch distribution \( g(l,t) \) can be calculated from:

\[
g(l,t) = \frac{2M(l,t)}{N(N-1)} \quad (4)
\]

where \( M(l,t) \) is the total number of pairs of particles with a length stretch ranging from \((l - \Delta l/2)\) to \((l + \Delta l/2)\) at time \( t \).

Using the length stretch distribution, the average length stretch \( \bar{l} \) at any time can be obtained through the following relation:

\[
\bar{l}(t) = \int_{(l-\infty)}^{(l=\infty)} lg(l,t) \, dt \quad (5)
\]

Time evolution of length stretch distributions and average values can provide a quantitative measure of analysis for distributive mixing efficiency.

Another way of looking at the overall distribution of the minor component in the mixing region (usually in batch type mixing equipment) is by following the dynamics of pairwise correlation functions \[18,19\]. For a more local analysis of mixing in batch systems, one can search for regions of the mixer void of any minor component elements. Such regions are called islands and they represent an obstacle to efficient mixing \[18\].

The different indexes of distributive mixing, namely length stretch distributions, pairwise correlation functions or volume fraction of islands provide an objective framework to quantify distributive mixing and to discriminate between various operating conditions and/or various mixer designs. Distributive mixing is related to randomization of a minor component throughout the system and therefore chaotic features of flow will enhance the process. Ottino and coworkers \[20-23\] have presented the most systematic approach to the modeling of distributive mixing by combining the kinematical foundations of fluid mechanics with chaotic dynamics.

In polymer processing equipment, the origin of chaos is related to complicated, time-dependent flow geometry. In chaotic systems there is a rapid divergence of initial conditions \[24\]. One way to quantify the divergence of initial conditions is by means of Lyapunov exponents. Positive values for the Lyapunov exponents indicate a more rapid divergence of the initial positions leading to better distributive mixing.

Simulating the mixing process in mixing equipment relies on the predictions of flow simulations. The computational schemes employed in most of the flow analyses in polymer processing are based on finite difference, finite element and boundary element methods. The purpose of these methods is to reduce the partial differential equations for the variables to a set of simultaneous equations for nodal variables at fixed points.
Most of the published literature on complex 3-D flow simulations in polymer processing equipment is based on either the Newtonian fluid or, at the next level of complexity, on the Generalized Newtonian Fluid model. Constitutive equations describing viscoelastic flow phenomena are generally numerically insoluble in multidimensional flows. One source of difficulty may arise from the singularity displayed in many of these constitutive equations when stress is plotted versus the rate of strain.

Larson [13] proposed constitutive equations for materials with a broad distribution of relaxation times using a power-law relaxation modulus. Such equations, although rigorously valid only for special flows (e.g., flows of constant stretch history) may represent a first step to a numerically tractable approximation of viscoelastic flows in complex flow geometries.

With today’s rapid advancement in computer technology, there is hope of solving fluid-flow problems involving complex fluids in complex geometries. However, challenges still remain in selecting constitutive equations which describe material flow behavior realistically, yet are tractable in numerical solutions and in the interpretation of flow simulation results in terms of process efficiency.

References

Membership Application Forms and other Information Available on the World Wide Web

Application forms for membership in the Society of Rheology can now be downloaded from the home page of the Society on the World Wide Web. The address is http://www.umecheme.maine.edu/sor/ Also available on the home page are abstracts of forthcoming papers in the Journal of Rheology and a listing of upcoming rheology meetings.

New WWW Site for History of Physics

Check out AIP’s new WWW site for the history of Physics, Astronomy and Geophysics at http://www.aip.org/history/ Information is available on AIP’s Niels Bohr Library and the Center for History of Physics. A featured Web exhibit is Einstein: Image and Impact which uses photographs, quotes, and text to present highlights of Albert Einstein’s life.

Meeting Announcements

March 24-26, 1997: Conference on Food Processing, Experimentation and Simulation, Lake Vyrnwy Hotel, mid Wales, UK. Contact: Dr. G.W. Roberts, Univ. of Wales. Fax: 01248 355881. e-mail: G.W.Roberts@bangor.ac.uk

May 7-10, 1997: 2nd Int. Conf. on Dynamics of Polymeric Liquids, Capri, Italy. Contact: Prof. K. Walters, Math. Dept., U of Wales, Penglais, Aberystwyth, Ceredigion, UK

June 1-6, 1997: Surfaces and Interfaces in Polymers and Composites, Lausanne, Switzerland. Contact: Prof. J.A.E. Manson via fax at 41 21 693 5880.

July 22-25, 1997: 2nd European Coating Symposium (Euromech 367), Strasbourg, France. Contact: Prof. P. Bourgin via fax at 33 88 61 43 00 or by e-mail at bourgin@imf.u-strasbg.fr

July 27-31, 1997: 2nd Pacific Rim Conference on Rheology, Melbourne, Australia. Contact: Dr. Y.L. Yeow, Dept. of Chemical Engrg., U. of Melbourne, Parkville, Vic. 3052, Australia. Fax: 61 3 9344 4153.

September 29-October 2, 1997: 8th International Conference on Mechanics and Technology of Composite Materials, Sofia, Bulgaria. Contact: Bulgarian Society of Rheology. Fax: 3592 703 433. E-mail: mezi@bgearn.acad.bg

October 5-8, 1997: 47th Canadian Chemical Engineering Conference (includes several rheology sessions), Edmonton, Canada. Contact: Prof. S.G. Hatzikiriakos Dept. of Chem. Engrg., University of British Columbia, Vancouver, BC V6T 1Z4. Fax: (604) 822-6003.


June 21-26, 1998: 13th US National Congress of Theoretical and Applied Mechanics, Univ. of Florida, Gainesville. Contact: Dr. M.A. Eisenberg, AeMES Dept., University of Florida, PO Box 116250, Gainesville, FL 32611. Tel: (7719) 333-4034; Fax: (352) 392-7303 e-mail meise@eng.ufl.edu

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<td><strong>REVENUES</strong></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Dues</td>
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<td>$56,000</td>
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<td>Interest</td>
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<td>16,500</td>
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<tr>
<td>Journal of Rheology</td>
<td>201,690</td>
<td>213,286</td>
<td>220,250</td>
<td>221,935</td>
<td>208,350</td>
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<td>Mailing List Sales</td>
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<td>1,040</td>
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<td>Annual Meetings</td>
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<td>3,728</td>
<td>-</td>
<td>15,889</td>
<td>6,000</td>
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<tr>
<td>Short Courses</td>
<td>5,250</td>
<td>4,520</td>
<td>-</td>
<td>-</td>
<td>10,000</td>
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<tr>
<td><strong>TOTAL REVENUE</strong></td>
<td>277,340</td>
<td>302,172</td>
<td>293,150</td>
<td>319,864</td>
<td>308,750</td>
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|                      |             |             |             |                |             |
| **EXPENSES**         |             |             |             |                |             |
| AIP Administrative Service | 7,000   | 7,000       | 7,000       | 7,000          | 7,000       |
| AIP Member Society Dues | 5,000   | 5,332       | 5,600       | 5,400          | 5,600       |
| AIP Financial Handling | 4,500   | 4,200       | 4,000       | 4,500          | 5,000       |
| AIP Physics Olympiad | 1,000     | 1,000       | 1,000       | 1,000          | 1,500       |
| Renewal Billing      | 1,500      | 971         | 1,500       | 1,300          | 1,500       |
| Journal of Rheology  | 201,625    | 192,317     | 222,135     | 207,910        | 208,350     |
| Bulletins & Abstracts | 7,000    | 9,026       | 3,000       | 4,050          | 15,000      |
| Short Courses        | 5,000      | 5,109       | -           | -              | 10,000      |
| Bingham Award        | 3,500      | 2,500       | -           | -              | 6,000       |
| Executive Cmt. Meeting | 6,500  | 4,665       | 6,500       | 6,200          | 7,500       |
| Pres. Discretionary Fund | 1,500  | -           | 1,500       | 500            | 1,500       |
| Treas. Discretionary Fund | 1,500 | 685         | 1,500       | 675            | 1,500       |
| Program Chm. Discre. Fund | 2,000 | -           | -           | -              | 4,000       |
| Secretarial Services | 1,000      | -           | 1,000       | 600            | 1,000       |
| Mailing              | 5,000      | 1,247       | 2,000       | 1,150          | 3,500       |
| Office Expenses      | 1,500      | 1,077       | 1,500       | 1,050          | 2,000       |
| Banking Services     | 100        | 30          | 120         | 150            | 150         |
| Liability Insurance  | 200        | 169         | 169         | 169            | 169         |
| Membership Directory | 3,500      | 1,292       | 6,500       | 8,380          | 5,500       |
| Membership Brochure  | 1,000      | -           | 1,000       | 715            | 1,000       |
| Accountant           | 1,500      | 1,214       | 1,500       | 1,330          | 1,500       |
| Student Member Travel Grant | 5,000 | 6,437       | 5,000       | 4,550          | 10,000      |
| Advance Deposit For Future Mtg. | 1,500 | 3,000       | 2,500       | 2,500          | 3,000       |
| Miscellaneous        | 5,500      | 4,511       | 1,500       | 3,500          | 1,500       |
| **TOTAL EXPENSE**    | 273,425    | 251,782     | 276,524     | 262,629        | 303,769     |

|                      |             |             |             |                |             |
| **NET INCOME**       | $3,915      | $50,390     | $16,626     | $57,235        | $4,981      |

|                      |             |             |             |                |             |
| **NET ASSETS AT YEAR END** | $406,311 | $463,546 | $463,546 | $463,546 | $463,546 |

'SACRAMENTO MEETING 1995'  
'PHILADELPHIA MEETING 1994'
Application for Membership in
THE SOCIETY OF RHEOLOGY

I wish to apply for membership in THE SOCIETY OF RHEOLOGY dating from January 19_____

(Family Name) __________________________ (Given Name) __________________________

Mail Address ________________________________________________________________

___________________________________________________________________________

Telephone Number __________________________ Fax Number _______________________

E-Mail Address __________________________

Please indicate in the boxes provided below the code letter from the list at the right, which best describes your areas of interest in order of decreasing importance.

☐ PRIMARY

☐ SECONDARY

☐ TERTIARY

Professional Affiliation

☐ Academic ☐ National Laboratory

☐ Industrial ☐ Other

I understand that my regular member's subscription to the Journal of Rheology is for my personal use, and not for library use.

___________________________________________________________________________

(Signature) (Date)

Enclose remittance in U.S. dollars (only) drawn on a U.S. bank and mail to: THE SOCIETY OF RHEOLOGY, c/o American Institute of Physics, 500 Sunnyside Boulevard, Woodbury, NY 11797-2999, (516) 576-2403.

☐ $40 for Regular Annual Dues ☐ $25 for Students

<table>
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<th>Complete if paying by credit card</th>
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