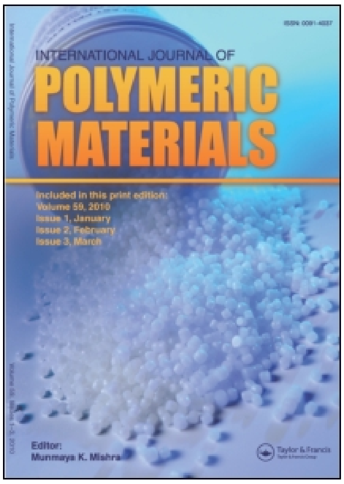

International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

The Recent Advances of Rheology in China

Ti-Qian Jiang[a]
[a] East China University of Chemical Technology, Shanghai, China

To cite this Article Jiang, Ti-Qian(1993) 'The Recent Advances of Rheology in China', International Journal of Polymeric Materials, 21: 1, 1 — 7
To link to this Article: DOI: 10.1080/00914039308048506
URL: http://dx.doi.org/10.1080/00914039308048506

Intern. J. Polymeric Mater., 1993, Vol. 21, pp. 1–7
Reprints available directly from the publisher
Photocopying permitted by license only

The Recent Advances of Rheology in China

TI-QIAN JIANG†

East China University of Chemical Technology, Shanghai, 200237, China

In this paper, some branches of rheology which have recently progressed faster than others in China and/or newborn branches are reviewed briefly.

KEY WORDS Rheology, petroleum, chemorheology, georheology.

Before 1985, rheology as a science has been known only by a few persons in China. In the six years since the foundation of the Chinese Society of Rheology in 1985, national meetings on Rheology have been held three times for an exchange of research results. Such an interscience among chemistry, mechanics, and engineering already extended to some industries, so that some branches have been formed, such as polymer processing rheology, petroleum rheology, food rheology, bio-rheology, rheology of multiphase systems, solid rheology and rheometry. Needless to say, rheology in China made great advances recently. The progresses in each branch will be reviewed briefly as follows:

1. INTERSURFACE RHEOLOGY

In the non-Newtonian flow mechanics field, the problems of polymer melt flow through annular converging dies, helical flow for a plastic fluid, flow in tubes, lubricate analysis, free jet and flow of foam have been studied recently. The study of wall slippage made notable progress in our country. Jiang[1] has given a formula for computing the slip velocity in a capillary tube:

$$V_s = a\tau_w^b \tag{1}$$

and a review.[2] A new field of study, intersurface rheology, was then initiated. Lu[3] has studied the wall slip velocity of polar non-Newtonian fluid, with the slip velocity of particles on the tube wall for blood given by:

$$V|_{r=a} = S_1\left[(k+\mu)\frac{dV}{dr} + k\omega\right] \tag{2}$$

wherein $S = \lambda_1 l/\mu_s$ denotes the coefficient of velocity slip; ω denotes the average

†Vice-chairman of Chinese Society of Rheology, Member of ICR.

velocity of particles. Using this model, the Fahraes-Lindquist effect of micropolar fluid can be explained. Tang *et al.*[4] studied the wall slip behavior of rubber compound melt in capillary extrusion, and a mathematical model describing the relationship between pressure change and variables in extrusion was presented:

$$P = P_L \exp\left[-\frac{2\mu}{R}(L - Z_1)\right] \tag{3}$$

and the critical length of slip is given by:

$$Z_1 = L + \frac{R}{2\mu}\ln\left(\frac{\tau_{RZ}}{\mu P_1}\right) \tag{4}$$

Combining Equations (3) and (4), the pressure change under experimental conditions can be predicted. Furthermore, Zhou *et al.*,[5] using the capillary wall slip correction, developed a new method with which the lubricating property of rubber lubricants can be characterized qualitatively. It was found that both the slip velocity and slip coefficient increase with the shear stress at the wall. It must be pointed out that Lu-Fan-Liu[6] have studied the flow enhancement of non-Newtonian flow with the aid of Laser Doppler Anemometry. A transition point of shear rate in the near wall region was found, and a pattern of wall slip flow structure follows directly from these results.

2. PETROLEUM RHEOLOGY

Applications of rheology to the petroleum industry are varied. Among those recently gaining still greater advances are as follows:

2.1. The Total Rheological Curve for Waxy Oil

To describe the rheological behaviors for Chinese waxy oil, after several years of hard work Luo[7] proposed a so-called total rheological curve for waxy oil, shown in Figure 1, which contains constructive yield, initial rheological curve (construction breakdown), stress decay curve, constructive dynamics equilibrium, and constructive recovery. He has also proposed a series of rheological equations to thoroughly describe the thixotropic characteristics of waxy oil.

2.2. The Constitutive Equation for Gels

Li and Jiang[8] have proposed a constitutive equation for Tian-Qing gel:

$$\tau = \frac{\tau_y}{\sqrt{\frac{1}{2}\,\mathrm{tr}\,D^2}}\mathbf{D} + \mathbf{H}\ \mathrm{tr}\,\tau^2 > 2\tau_y^2 \tag{5}$$

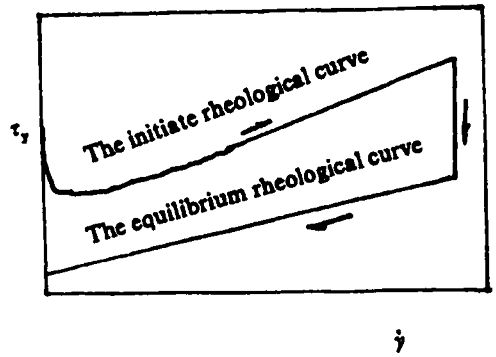

FIGURE 1 The total rheological curve for waxy oil.

wherein

$$\mathbf{H} = \int_{-\infty}^{1} G[(t - t'), \mathrm{II}_c]\mathbf{C}^{-1}\, dt' \tag{6}$$

The above equation not only can satisfy Von-Mises's yield criterion but also is suitable for predicting the rheological properties of Xanthan gum and HGP gels.

2.3. The Rheological Behavior of Foam

Foam is a kind of fracturing liquid in EOR which is widely used in low pressure oil wells. Jiang,[9] based on a three dimensional construction as a theoretical model of high concentration foams, developed an expression for the yield stress of foam:

$$\tau_y = 0.6382\, \frac{\sigma}{R}\, \Phi^{1/3} F_{\max}(\Phi, \Delta x, \Delta y, \Delta z) \tag{7}$$

where $F_{\max}(\Phi, \Delta x, \Delta y, \Delta z)$ can be obtained from a special figure. It has been shown that this equation is better than that given by Princen based on a two dimensional construction. A theoretical stress tensor model that includes surface tension forces and viscous forces was developed by Zhou and Jiang[10] based on the proposition of Khan and Armstrong[11]:

$$\tau = -\frac{1}{V}\int_A \sigma(\delta - nn)\, dA - \frac{\mu}{V}\int_{V-V_g} \dot{\gamma}\, dV \tag{8}$$

and they have calculated the shear stress and normal stress differences by computer. Comparison between the theoretical results and experimental data is in good agreement.

3. CHEMORHEOLOGY AND ELECTRORHEOLOGICAL TECHNOLOGY

Chemorheology is the study of the dependence between chemical reaction and rheological properties. So far only one system, RIM of Polyurethane, was commercialized. This is a popular research subject in modern rheology. The principal study of it was begun in China. The chemorheological properties of RIM Polyurethane under both adiabatic and isothermal conditions were measured simultaneously by Pan *et al.*[12] The change of viscosity with time is shown in Figure 2. Besides, it is found that the synergistic effect of catalyzer seems correct. Further study of this problem is still needed.

Electrorheological effect means that the rheological properties of fluid change under the influence of a strong electronic field. The effect can cause sudden change of viscosity from low to high, producing a viscoplastic solid with yield stress. When the electronic field is removed, the properties may return to their original state under very short time; such a fluid is called an electrorheological fluid and the special technology is called electrorheological technology. It is a newly developed technology for the future, already being used by scientists in many countries. In 1989, August 7–9, the second International Conference on ER fluid was held at North Carolina State University. The research work in our country was begun. Wei[13] has given a review on the basic concept of ER technology, the prospect of its application in engineering, the composition and properties of ER fluid and the trends of recent research. Liang *et al.*[14] published two articles about the initial

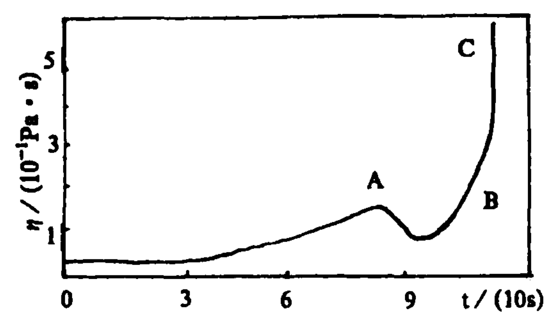

FIGURE 2 The viscosity-time relation for RIM of Polyurethane under isothermal conditions.

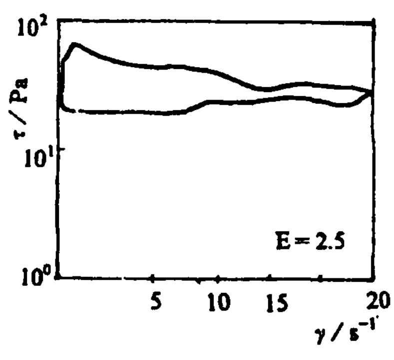

FIGURE 3 The thixotropic loop of ERF under electronic field.

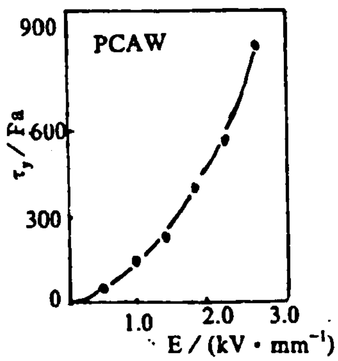

FIGURE 4 The variance of yield stress with the field strength.

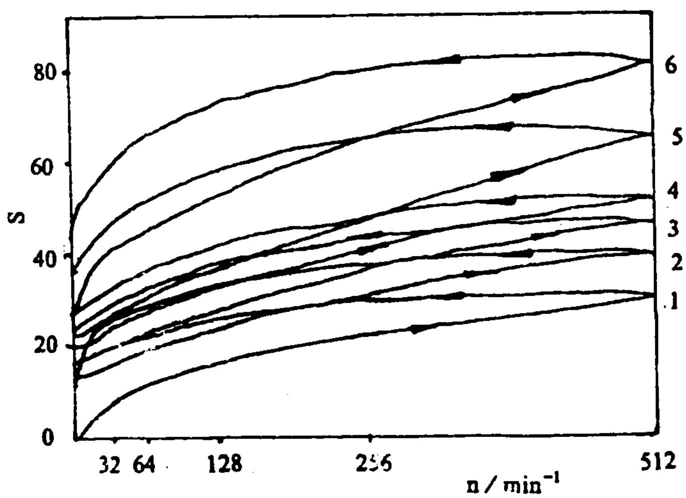

FIGURE 5 The periodical shear curve of debris flows.

research results of ERE, another first for China. They pointed out that ER fluid did not show the stress overshot behavior for viscoelastic fluids but appeared to exhibit plastic characteristics. The system containing water displayed the thixotropic effect shown in Figure 3. ERE would be reduced by adding dispersants. Furthermore, it was found that there was a critical field strength for most of the systems. It was around 0.25 kV/mm, below which there was no ERE. The electro-viscosity was in direct proportion to the first power of field strength but to the second power of the yield stress as shown in Figure 4. Moreover the particle concentration was also an important factor affecting ERE.

4. GEORHEOLOGY: DEBRIS FLOW

Debris flow is a kind of abruptly occurring natural calamity in mountainous areas which seriously impacts the economic construction and security of inhabitants. The study of the formation, movement and depositing mechanism of debris flow now is an important reducing calamity research work. At first, Wang[15] discovered that the viscous debris flow was not only a Bingham liquid but also thixotropic liquid. Having studied the relation between viscosity and time for the slurry of viscous debris flow, Zhao[16] found that the slurry showed some anti-thixotropic rheological behavior. The slurry thickened at shearing time but its structure was partly broken at rest. Wang *et al.*[17] considered that the rheological movement equation of debris flow could be written as follows:

$$\frac{d\gamma}{dt} = \frac{1}{\gamma}\frac{d\tau}{dt} + \frac{1}{\eta}(\eta - \tau_y) \tag{9}$$

When $d\tau/dt = 0$, it became the Bingham equation, but when $d\tau/dt = 0$, stress decayed with time and different depositing features were formed.

This problem is an important example of the application of suspension rheology, which is worth more attention and further investigation.

5. COMPUTATIONAL ANALYTICAL RHEOLOGY

When computational rheology is developing rapidly, a new research direction like computational analytical methods applied to rheology appears. Using some special computer programs such as 'Macsyma,' computational analytic rheology can be used to finish automatically the dully manual derivations and calculations in research work. Han[18] used the program of the University of Darmstadt in Germany to study the unsteady flow of viscoelastic fluids in a coaxial cylinder. The analytical expressions of the second order and third order approximation for this problem have been obtained through computer driven derivations. It is evident that this method is full of vitality and the future of its application is promising. This is an excellent example of the application and development of artificial intelligence on rheology.

6. RHEOLOGY FRACTURE

On the basis of criticism and the lessons of classical fracture mechanics and classical thermodynamics, the concepts of rheological fracture were established by Yuan.[19] This is a significant newly developed branch in modern fracture mechanics which has been studied for several years and is supported by the national natural science foundation of China and the United States. Researchers think that the extension of cracks is not a purely mechanical process, but a combined thermo-mechanical and thermorheological process. Rheology and fracture are not independent of each other. The combination of the crack field and the gage field builds a bridge between the microcosm and the macrocosm. The development of this branch will provide the foundation of fracturing control and the design of crack prevention. It is the latest development of solid rheology.

References

1. T. Q. Jiang, A. C. Young and A. B. Mentzner, The Rheological Characterization of HGP Gels: Measurement of Slip Velocities in Capillary Tubes, *Rheol. Acta*, **25**, 397–404 (1986).
2. T. Q. Jiang, *Study on the Wall Slip Phenomena and its Application*, S. F. Han & D. C. Wu (Eds.): Advances in Rheology **2**, 2–3 (1987).
3. Z. J. Lu and G. P. Zheng, *The Wall Velocity Slip of Polar Non-Newtonian Fluid*, in T. Q. Jiang (Ed.): Advances in Rheology, Shanghai: ECUCT Press, 69–71 (1990).
4. J. Z. Liang and G. J. Tang, *Research on Wall Slip Behavior of Rubber Compound Melts in Capillary Extrusion*, ibid, 373–376.
5. Y. H. Zhou, J. Z. Li, W. D. Wu and Z. L. Sun, *A New Method of Characterizing Lubricating Property of Rubber Lubricants*, ibid, 59–61.
6. Z. M. Lu, C. Fan and Z. C. Liu, *Investigation for the Flow Enhancement of Non-Newtonian Flow Using Laser Doppler Anemometry*, ibid, 77–79.
7. T. H. Lou, *The Total Rheological Curve for Waxy Oil*, ibid, 91–93.
8. J. Li and T. Q. Jiang, *A Study of Elastico-Viscoplastic Constitutive Equation for Tian Qing Gel*, ibid, 185–189.
9. Y. Xia, J. Y. Chu and T. Q. Jiang, *Study on the Yield Stress of Highly Concentrated Foams*, Xth Internl. Congress on Rheol., Sydney, 383–385 (1988).
10. C. D. Zhou, J. Y. Chu and T. Q. Jiang, *Study on the Shear Stress and Normal Stress of Foam*, ibid, 165–171.
11. S. A. Khan and R. C. Armstrong, *J. Non-Newtonian Fluid Mech.*, 25 (1987).
12. B. L. Pan, T. W. Chan, Z. G. Jiang and P. Zhu, *A Study of the Chemorheological Properties of RIM Polyurethane*, in T. Q. Jiang (Ed.): Advances in Rheology, Shanghai: ECUCT Press, 1990, 274–279.
13. C. G. Wei, *Research on the Electro Rheological Technique and the Prospect of It's Engineering Application*, J. Beijing Inst. Technol., **3**, 104–108 (1989).
14. R. F. Liang, Y. Z. Xu and L. H. Shi, *Study on Electro Rheological Effect*, in T. Q. Jiang (Ed.): Advances in Rheology, Shanghai: ECUCT Press, 180–184 (1990).
15. Y. B. Wang and S. F. Han, *Investigation on Thixotropic Behavior of Viscous Debris Flow*, ibid, 86–87.
16. H. L. Zhao, *Experimental Study on the Viscosity-Time Relation of the Slurry of Viscosity Debris Flow*, ibid, 329–331.
17. Y. Y. Wang, J. S. Wu, G. Xong and B. Y. Yan, *An Approach to Stress and Depositing Feature for Debris Flow*, ibid, 347–349.
18. S. F. Han, *Computational Analytical Approach to Mechanics of Viscoelastic Fluid*, ibid, 6–11.
19. L. W. Yuan, *The Status Quo of Rheological Fracture Theory*, ibid, 1–5.