Extensional flow in the literature - a naïve assessment ⋆

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Abstract

This note reviews the occurrence of extensional flow topics in the rheological literature. A simple approach is taken so the results have to be regarded with caution.

1 Introduction

This paper and its companions celebrate the contributions of Trouton in 1906 [1] and Fano in 1908 [2] to rheology and to extensional flow in particular. An account of the genesis of this set of papers may give the reader some idea of what to expect. There were four main sections in the talk given at the Lake Vyrnwy conference: history (1900-1950), extensional flow in the literature, a practical case study, and a few remarks on extensional viscosity and unsteady flows. The historical section became the first half of the first paper [3], covering Trouton, Fano and then early work in the two areas inspired by them, spinnability and viscosity measurement. In writing and discussing a draft paper, it became clear that the last section of the talk was important and this has been developed in a companion paper on extensional viscosity [4]. Part of the account of extensional flow in the literature consisted of some rather naïve counting of occurrences of key words and this is offered here (on the web). The practical case study, on the effect of additives in reducing the risk of fire from aircraft fuel spillage, generated much interest at the conference and this is also included in the first paper [3]. Finally, it is planned to prepare an annotated bibliography [5].

⋆ Based on part of the talk delivered at the INNFM conference, Lake Vyrnwy, Wales in March 2005 with the title "Ninety-nine years of extensional flow".

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Tensile stress contribution of flow-oriented slender particles in non-newtonian fluids,	J.D. Goddard	1–17
Elastico-viscous squeeze films. part I,	G. Brindley, J.M. Davies & K. Walters	19–37
The dissipative mechanism in flowing polymers: theory and experiments,	G. Astarita & G.C. Sarti	39–50
Non-newtonian flow caused by an infinite rotating disc,	E.W. Williams	51–69
An experimental study of nonrheometric flows of visco-elastic fluids : I. flow into a re-entrant tube,	E.T. Busby & W.C. MacSporran	71–82
Converging flow of a viscoelastic liquid,	J.R. Black & M.M. Denn	83–92
The triple jet: influence of shear history on the stretching of polymer solutions,	D.R. Oliver & R.C. Ashton	93–104

Table 1
Contents of JNNFM, Issue 1, January 1976

2 Extensional flow in the literature

The first paper in this series [3] discussed the progress made by the organization of a number of conferences and workshops devoted wholly or in part to extensional flow between 1971 and 1989. Special issues of the Journal of Non-Newtonian Fluid Mechanics (JNNFM), often recording important papers from such conferences, have been devoted to extensional flow since very soon after the journal was founded.

Here we make a brief informal assessment of the amount that has been published that is obviously concerned with extensional flow. We make a start with the first issue of JNNFM in 1976, Table 1, with three papers (by Goddard, Black & Denn and Oliver & Ashton) on extensional flow out of the seven published. Walters and Barnes [6] give a graphical representation of progress in the period up to 1980, showing the rise in research activity in extensional flow and how this is sustained, in contrast to some other rheological topics (Fig. 1). For an assessment of current interest or activity in extensional flow we look at the first two issues of the new publication from the British Society of Rheology, Rheology Reviews [7,8], see Table 2. At first sight the tables of contents suggest a complete absence of attention to extensional flows in 2003 and limited attention (to failure and recovery in elongational flow and to breakup of non-Newtonian liquid jets) in two out of the seven 2004 articles. In order to assess how much extensional flow these cover, a comparison of frequency of occurrence of a selection of words and phrases was undertaken. This is rela-

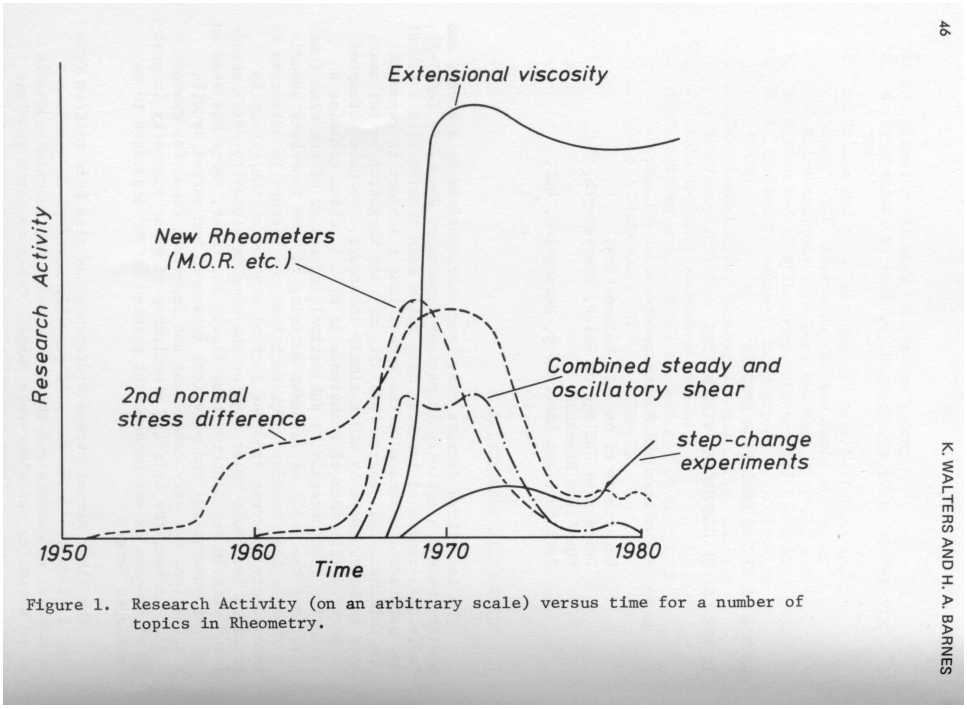

Fig. 1. Research activity in rheological topics (Walters and Barnes [6, Fig. 1]).

tively easy to do with the publications being available on CD-ROM as well as in book form (though care must be taken with, for example, the completely unrelated usages of extension *tout court*). As a check on the method and to give the numbers some sort of meaning, the numbers of occurrences of some words and phrases associated with other common areas of rheology were also counted. Table 3 shows the frequencies of occurrence of the indicated words and phrases in each year and in Rheology Reviews to date. Frequency of occurrence of the six chosen extensional flow phrases in each article is shown in Table 4.

No occurrences were found of words commencing **spinn** (e.g. spinnability, spinnbarkeit or even spinning), the phrases "**pure shear**", "**exponential shear**", "**rod climbing**" or the words **Fano**, **siphon** and **thixotropy**, while **thixotropic**, **converging**, **biaxial** and **pseudoplastic** each occur only once in the two volumes and **Trouton** and **Deborah** each occur only three times. The phrase "normal stress" occurs 97 times, including the 22 occurrences of each of "**first normal stress**" and "**second normal stress**" noted in Table 3; this is much the same as the various synonyms for **fibre** and half as often as the combined occurrences of **extensional** and **elongational**.

Whether the inferences one draws are on changing fashions in rheological research or on the choices made by the editors of the first two years of Rheology Reviews is a matter of personal choice. There is certainly more attention to extensional flow than the titles of the articles alone suggested and we also

Rheology Reviews, 2003 [7]

A review of the rheology of filled viscoelastic systems,	Howard A. Barnes	1–36
Simple non-equilibrium thermodynamics applications to polymer rheology,	Anthony N. Beris	37–75
Rheology of mobile interfaces,	Gerald G. Fuller	77–123
Compressive rheology : an overview,	Ross G. de Kretser, David V. Boger & Peter J. Scales	125–165
Finite element methods for integral viscoelastic fluids,	Roland Keunings	167–195
Present puzzles of entangled polymers,	Tom C. B. McLeish	197–233

Rheology Reviews, 2004 [8]

Failure and recovery of entangled polymer melts in elongational flow,	Yogesh M. Joshi & Morton M. Denn	1–17
Rheology of food dispersions,	Críspulo Gallegos, José M. Franco & Pedro Partal	19–65
Micro-macro methods for the multi-scale simulation of viscoelastic flow using molecular models of kinetic theory,	Roland Keunings	67–98
Dynamics of a liquid drop in a flowing immiscible liquid,	Stefano Guido & Francesco Greco	99–142
Drag reduction in turbulent flow of polymer solutions,	Michael D. Graham	143–170
Self-similar breakup of non-Newtonian liquid jets,	Michael Renardy	171–196
Recent developments on the slow viscoelastic flow past spheres and bubbles,	Bruce Caswell, Octavio Manero & Baltasar Mena	197–223

Table 2
Contents of Rheology Reviews, 2003 and 2004

note less attention to some classical areas of rheology than would have been observed 50 or even 25 years ago. The absence of the names such as Trouton, Fano and Deborah seems to show a lack of attention to history; such a lack may not be unexpected in reviews of the current state of the art. Hopefully, an article such as the first in this series [3] will redress the balance.

	Word or phrase	RR 2003	RR 2004	Total
(a)	**elongational viscosity**	8	4	12
(b)	**extensional viscosity**	15	10	25
(c)	**elongational** (not viscosity)	3	52	55
(d)	**extensional** (not viscosity)	40	51	91
(e)	**filament, fibre or thread**	51	47	98
(f)	**breakup or break-up**	1	151	152
	first normal stress	14	8	22
	second normal stress	17	5	22
	extrudate swell (or die swell)	42	2	44
	Weissenberg	8	49	56

Table 3
Frequency of occurrence of phrases in Rheology Reviews

Individual articles, 2003

Author	*(a)*	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*
Barnes	8	13	0	5	45	0
Beris	0	2	1	2	0	0
Fuller	0	0	2	30	2	1
de Kretser	0	0	0	0	0	0
Keunings	0	0	0	0	4	0
McLeish	0	0	0	3	0	0

Individual articles, 2004

Author	*(a)*	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*
Joshi	0	0	16	9	5	1
Gallegos	0	0	0	0	2	0
Keunings	0	0	1	7	9	1
Guido	0	0	29	10	15	72
Graham	0	3	0	14	5	0
Renardy	3	0	3	0	11	77
Caswell	1	7	3	11	0	0

Table 4
Frequency of occurrence of extensional flow phrases in Rheology Reviews articles

3 Concluding remarks

This is work in progress and may be updated from time to time.

References

[1] F.T. Trouton, On the coefficient of viscous traction and its relation to that of viscosity Proc. Roy. Soc., A77 (1906) 426-440.

[2] G. Fano, Contributo allo studio dei corpi filanti *(Contribution to the study of thread-forming materials)*, Archivio di fisiologio, 5 (1908) 365-370.

[3] C.J.S. Petrie, One hundred years of extensional flow, J. Non-Newtonian Fluid Mech., 254 (2006) 1-14.

[4] C.J.S. Petrie, Extensional viscosity: a critical discussion, J. Non-Newtonian Fluid Mech., 254 (2006) 15-23.

[5] C.J.S. Petrie, Extensional flows: an annotated bibliography, *In preparation*

http://www.staff.ncl.ac.uk/chris.petrie/papers/petrie06d.pdf

[6] K. Walters and H.A. Barnes Anomalous extensional flow effects in the use of commercial rheometers, in G. Astarita, G. Marrucci and L. Nicolais (Eds.), Rheology, Volume 1: Principles *(Proceedings of the VIIIth International Congress on Rheology)*, Plenum Press, New York (1980) pp.45-62.

[7] Rheology Reviews 2003, D.M. Binding and K. Walters (Eds.), British Society of Rheology, Aberystwyth, 2003,

http://www.bsr.org.uk/

[8] Rheology Reviews, 2004, D.M. Binding and K. Walters (Eds.), British Society of Rheology, Aberystwyth, 2004

http://www.bsr.org.uk/