The Nonlinear History of Fibre Flow Research. Part 2: Continuation, Reflections and Suggestions

Ulf Björkman

Department of Fibre and Polymer Technology, Royal Institute of Technology (KTH), 100 44 Stockholm, Sweden

Email: ulf@kth.se
Fax: x46.8.7908101

Received: 19.11.2007, Final version: 18.12.2008

Abstract:
Technical fibre flows are normally flocky but have theoretically mainly been treated as individual fibre flows. The reason for this can only be understood through the subject's historic development. In Part 1 of this investigation the origin of fibre flow research was traced to the beginning of the 19th century, and was followed through its formative years at the first half of the 20th century up to about WWII. This second and final part takes us up to about the 1960s when the present main theoretical research tradition had been firmly established. An example of an alternative approach is given. Finally, some suggestions for future work are advanced. In Appendix methods of characterising the inner geometry of technical fibre suspensions are discussed

Zusammenfassung:
Technische Faserströmungen sind normalerweise flockig, wurden allerdings theoretisch üblicherweise als Strömung von individuellen Fasern behandelt. Die Ursache dafür kann nur in der historischen Entwicklung dieses Bereiches gesehen werden. Im ersten Teil 1 dieser historischen Untersuchung zur Forschung an Faserströmung wurden die ersten Untersuchungen am Anfang des neunzehnten Jahrhunderts und die prägenden Entwicklungen im zwanzigsten Jahrhunderts bis zum Beginn des Zweiten Weltkrieges betrachtet. Dieser zweite und abschließende Teil erstreckt sich bis ungefähr 1960, dem Zeitpunkt wo sich die heute übliche Tradition fest etabliert hat. Im zweiten Teil wird auch eine alternative Behandlung technische Faserströmung vorgestellt. In Appendix werden zudem Methoden erläutert, die die innere Geometrie technische Fasersuspensionen diskutieren.

Résumé:
Le courant des suspensions techniques fibreuses est normalement fouleuse, mais à été surtout modelé comme courant de fibres individuelles. La raison de cela ne peut être comprise que par le développement historique de ce sujet. La première partie de cette investigation historique traitait de l'origine de la recherche sur le courant des suspensions techniques fibreuses, dont le point de départ peut êtres placés au début du dix-neuvième siècle, et a été poursuivie dans les années formatives du début du vingtième siècle jusqu'à la seconde guerre mondiale. La présente seconde partie nous mène au environ de 1960 quand l'actuelle recherche théorétique est définitivement établie. Un exemple d'une vue alternative est présenté. Finalement, quelques suggestions de travaux futurs sont présentées. En Appendice, quelques méthodes de mesure de géométrie intérieure des suspensions techniques fibreuses sont discutées.

Key words: fibre flow, fibre suspension, research history

1 INTRODUCTION

The first part of this review [77] established that the theoretical development of fibre flow research was founded rather on mid-19th century microhydrodynamics and early 20th century physical and colloid sciences than on fibre flow experiments carried out in the fibre-based process industry.

Before continuing this scientific/cultural sweep is helpful to define some terms. A *floc* here means a gathering of objects, *flocky* something consisting of flocs *or* giving the impression of being that. *Flockiness* is the degree of agglomeration *or* the character that gives the flocky appearance. *Flocculation* is the classical process (e.g. colloidal) of forming flocs by bringing objects together through directed motion (orthokinetic) or undirected (perikinetic), the latter often being what remains when the first has ceased, e.g. Brownian motion. It should, however, be pointed out that this classification is not all-embracing. For example, it does not contain the technical fibre systems considered in this work. Flocs may namely form through the break-up of a fibre network (*splitulation*) that has formed by other means than flocculation, e.g. through growth in a tree.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

Finally, to optimize product properties (e.g. of paper sheet) technical fibre suspensions normally a mixture of different fibres and/or filler of other types are used. The question is how far it is then meaningful to carry on modelling with the ambition of depicting what is actually going on. An alternative approach is to treat such practical problems more empirically. The author is inclined to believe that the really rational way of dealing with such problems is empirically and in close connection with the production where also natural variations in the raw material can be coped with directly. The problem is to not overwork the modelling but keep it on a reasonable level with respect to what can be measured and utilised.

REFERENCES

References [1] to [76] can be found in Part 1 of this work, i.e. in Reference [77].

[77] Björkman U: The nonlinear history of fibre flow research: Part 1. Background and beginning, Appl. Rheol. 18 (2008) 23974.

[78] Björkman U: Flow of flocculated fibres, ISBN 91-7170-178-8, KTH Högskoletryckeriet, Stockholm, 1999.

[79] Björkman U: Floc dynamics in flowing fibre suspensions, Nord. Pulp. Pap. Res. J., 18 (2005) 247.

[80] Ostwald W: Die Welt der vernachlässigten Dimensionen, Steinkopff, Dresden, 1916.

[81] Börje Steenberg, professor in Paper Technol., KTH, Stockholm, 1949-79. Personal comm., 1991-2007.

[82] Mason SG, Maass O: Measurement of viscosity in the critical region. Ethylene, Can. J. Res., 18B (1940) 128.

[83] Mason SG: The flocculation of cellulose fibre suspensions, Pulp Paper. Mag. Can., 49 (1948) 99.

[84] Mason SG: The motion of fibres in flowing liquids, Pulp Pap. Mag. Can., 51 (1950) 93.

[85] Hubley CE, Robertson AA and Mason SG: Flocculation of suspensions of large particles, Can. J. Res., 28 (1950) Sect. B, 770.

[86] Mason SG: The flocculation of pulp suspensions and the formation of paper, TAPPI, 33 (1950) 440.

[87] Mason SG: Rheology of suspensions, in "Rheology," vol. 2. Proc. 8th Int, Congr. Rheol., eds. G Astarita et al., Naples, p. 631, Plenum, New York, 1980.

[88] Goldsmith HL, Mason SG: The microrheology of dispersions, in “Rheology. Theory and Application,” vol. 4, ed. FR Eirich, Academic Press, New York, 1967.

[89] Kerekes RJ, Soszynski RM and Tam Doo PA: The flocculation of pulp fibres, in “Paper making raw materials”, 8th Fundam. Res. Symp., 265, Mech. Eng. Publ., Oxford, 1985.

[90] Forgacs OL, Robertson AA and Mason SG: The hydrodynamic behaviour of papermaking fibres, Pulp Pap. Mag. Can., 57 (1958) 117.

[91] Andersson O, Brunsvik J-J: Flocculation of streaming fibre suspensions, Svensk Papperstidn., 64 (1961) 493.

[92] Steenberg B: Rheomembrances, Trans., Nord. Rheol. Soc., vol. 15 (2006) 1.

[93] van de Ven TGM: Colloid hydrodynamics, Academic Press, London, 1989.

[94] van de Ven TGM: Interactions between fibres and colloidal particles subjected to flow, Ann. Trans. Nord. Rheol. Vol. 14 (2006) 14.

[95] Whitehead AN: A second approximation to viscous fluid motion, Quart. J. Math., 23 (1889) 143.

[96] Oseen CW: Über der Stokessche Formel und über eine verwandte Aufgabe in der Hydromekanik, Arkiv mat. astr fys., (1910) 6,

[97] Oseen CW: Neuer Methoden und Ergebnisse in der Hydrodynamik, Akad. Verlagsgesellschaft GmbH, Leipzig, 1927.

[98] Faxén H: Einwirkung der Gefäßwände auf den Wiederstand gegen die Bewegung einer kleinen Kugel in einer zähen Flüssigkeit, Diss. Upsala Univ., Uppsala, 1921.

[99] Faxén H: Der Wiederstand gegen die Bewegung einer starren Kugel in einer zähen Flüssigkeit, die zwischen zwei parallelen ebenen Wänden eingeschlossen ist, Ann. Physik, 68 (1922) 89.

[100] Lamb H: Hydrodynamics, 4–6th eds., Cambridge Univ. Press, 1927 – 32.

[101] Lindgren RE: The motion of a sphere in an incompressible viscous fluid at Reynolds numbers considerably less than one, Phys. Scripta, 60 (1999) 97.

[102] Taylor GI: The viscosity of a fluid containing small drops of another fluid, Proc. Roy. Soc. A, 138 (1932) 41.

[103] Taylor GI: The formation of emulsions in definable fields of flow, Proc. Roy. Soc. A, 144 (1934) 501.

[104] Vand V: Viscosity of solutions and suspensions, J. Phys. Colloid Chem., 52 (1948) 277.

[105] Simha R: A treatment of the viscosity of concentrated suspension, J. Appl. Phys., 233 (1952) 1020.

[106] Frankel NA, Acrivos A: On the viscosity of concentrated suspension of solid spheres, Chem. Eng. Sci, 22 (1967) 847.

[107] Batchelor GK: The stress generated in a non-dilute suspension of elongated particles by pure straining motion, J. Fluid. Mech, 46 (1967) 813.

[108] de Gennes P-G: Conjecture on the transition from Poiseuille to plug flow in suspensions, J. de Phys., 40 (1979) 783.

[109] Happel J, Brenner H: Low Reynolds number hydrodynamics; With special applications to particulate media, Prentice Hall, 1973, 2nd ed. Nordhoff Int. Publ., Leyden, 1965.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

[110] Schowalter WR: Mechanics of non-Newtonian fluids, Pergamon, Oxford, 1978.
[111] Kim S, Karrila SJ: Microhydrodynamics: Principles and selected applications, Butterworth, Boston, 1991.
[112] Crochet J, Davis AR and Walters K: Numerical simulation of non-Newtonian flow, Elsevier, Oxford, 1984.
[113] Schmid CF, Switzer LH and Klingenberg DJ: Simulations of fiber flocculation: Effects of fiber properties and interfiber friction, J. Rheol., 44 (2000) 781.
[114] Switzer LH, Klingenberg DJ: Simulation of fiber floc dispersion in linear flow fields, Nord. Pulp Pap. Res. J. 18 (2003) 141.
[115] Meyer R, Wahren D: On the elastic properties of three-dimensional fibre networks, Sv. Papperstidn. 67 (1964) 432.
[116] Deng M, Dodson CTJ: Paper: An engineered stochastic structure, Tappi Press, Atlanta, 1994.
[117] Björkman U: Fibre flow research history, Part II. Continuation, Trans. Ann. Trans. Nord. Rheol. Soc., vol. 15 (2007), 87.
[118] Björkman U: Mycelial flow, ISBN 91-7170-085-4, KTH Högskoletryckeriet, Stockholm, 1991.
[119] Chain EB, Gualandi G: Aeration studies, Ist. sup. Sanit. (English Edn.), 17 (1954) 1109.
[120] Roels JA, van den Berg J and Voncken RM: The rheology of fermentation broths, Biotechnol. Bioeng., 16 (1974) 181.
[121] Duffy GG: The importance of mechanistic-based models in fibre suspension flow, Appita, 53 (2000) 337.
[122] Meyer H: An analytical treatment of the laminar flow of annulus forming fibrous suspensions in vertical pipes, Tappi, 47 (1964) 78.
[123] Moller K, Duffy GG and Titchener AL: The prediction of pipe friction losses from rotational viscometry, Sv. Papperstidn., 76 (1973) 493.
[124] Truesdell C, Toupin R: The classical field theories in "Hanbuch der Physik", III/1 ed. S. Flügge, Springer, Berlin, 1960.
[125] Ball JM, James PD: The scientific life and influence of Clifford Ambrose Truesdell III, Arch. Rational Mech. Anal., 161 (2002) 1.
[126] Eckert M: The dawn of fluid dynamics, Wiley-VCH, Weinheim, 2006.
[127] von Kármán T, Edson L: The wind and beyond, Little Brown, Boston, 1967.
[128] Anderson, JD: Introduction to flight, 4th ed., McGraw-Hill, New York, 2000.
[129] Grandin K: Ett slags modernism i vetenskapen: Teoretisk fysik i Sverige under 1920-talet, (in Swedish), Dept. Hist. Sci. Ideas, Report no. 22, Uppsala Univ. (1999).
[130] Reiner M: Deformation, strain and flow, Lewis, London, 1960.
[131] Einstein A: The collected papers of Albert Einstein, Ed. D Kormos Buchwald, Princeton Univ. Press, Princeton, 2004.
[132] Hildebrand S, Tromba A: The parsimonious universe, Springer-Verlag, New York, 1996.
[133] Hart C: The prehistory of flight, Univ. Calif. Press, Berkeley, 1985.
[134] Barnes, HA, Edwards, MF, Woodcock, LV: Applications of computer simulations to dense suspension rheology, Chem. Eng. Sci. 42 (1987) 591.
[135] Astarita G, Marucci G: Principles of non-newtonian fluid mechanics, McGraw Hill, London, 1974.
[136] Nicolis G, Prigogine I: Exploring complexity, Freeman, New York, 1989.
[137] Truesdell C: Phys. Bl. Zu den Grundlagen der Mechanik und Thermodynamik, 16 (1960) 512.
[138] Oseen CW: Die anisotropen Flüssigkeiten, Tatsachen und Theorien, Gebr. Bornträger, 129.
[139] Oseen CW: Contributions à la theorie des fluids anisotropes, 22. Theorie des essaims, Arkiv Mat. Fys. Astr., 26A, N:o 5 (1937) 1.
[140] Oseen CW: Beiträge zur Theorie der anisotrpen Flüssigkeiten, XVI. Thermodynamische Theorie der Bewegung einer anisotropen Flüssigkeit, Arkiv Mat. Fys. Astr., 23A, N:o 3 (1932) 1.
[141] Bingham E: Fluidity and plasticity, Mc Graw-Hill, New York, 1922.
[142] Truesdell C: An idiot's fugitive essays on science, Springer, New York, 1984.
[143] Jou D, Casas-Vázquez J, Lebon G: Extended irreversible thermodynamics, Springer, Berlin, 1996.
[144] Björkman, U: Properties and principles of mycelial flow: Experiments with a tube rheometer, Biotechnol. Bioeng. 29 (1986) 114.
[145] Barnes, HA: The "Yield Stress Myth?" paper – 21 years on, Appl. Rheol. 17 (2007) 43110-1.
[146] Cumberland DJ, Crawford RJ: The packing of particles, Elsevier, Amsterdam, 1987.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org