Introduction to "The Diabolical Case of the Recurring Yield Stress"

To say that a yield stress doesn't exist is equivalent to claiming there is no such thing as a Newtonian fluid, which of course is true in the strictest academic sense. Our molecular dynamics colleagues will clearly show that if the timescale of observation is short enough then Newtonian fluids will exhibit viscoelastic properties. The same thing I am sure is true with materials that exhibit a yield stress. Perhaps if we are willing to wait long enough we will see yield stress materials flow. Often we do not have enough time to wait!!

In our laboratories we have had much interaction with industry, where we have had to deal with yielding in the truest sense of the word, i.e., how much energy is required for the pipeline to flow, what slope will be formed in a waste deposit, will the suspension settle, and on what time frame? We have even seen complicated materials like waxy crudes where one can observe from dynamic property measurements a transition from Hookean elasticity through to a creep like phenomena, through to abject failure and yielding.

The following is an amusing dialogue presented at the Nordic Society of Rheology meeting held in the Faroe Islands in June 2003. I had the privilege of being there as the guest of the Nordic Society of Rheology. What a great meeting. Conclusions reached by Holmes and Watson (Mats Larsson and Niall Young) are similar to the outcome from the University of Wales Institute of Non-Newtonian Fluid Mechanics conference on rheology held on 14-16 April 2003 where one session was devoted to the yield stress, where Gareth McKinley, Howard Barnes and myself each made plenary contributions. I now believe the controversy on yielding, which probably never should have existed, is over and the conclusions reached in the Homes and Watson debate are consistent with the general consensus. Enjoy the paper!

David V Boger
Laureate Professor, and
Director, Particulate Fluids Processing Centre
The University of Melbourne

The Diabolical Case of the Recurring Yield Stress

Dr. J.H. Watson

c/o 221B Baker Street, London, England

Abstract:
The yield stress has, since its conception, been a source of fierce and often acrimonious debate. This review article deals with the issue, looking at problems related to the meaning of the definition, timescale of the observation, whether the yield stress is a property of concentrated suspensions or is linked to the strength of coherent network structures. We discuss the problematic nature of how to measure the yield stress, directly or indirectly, and examples of the vane geometry are given. Throughout, absolutist and realist theories and evidence are presented and a consensus is finally drawn. Rheologists should embrace the consequences of the absolutist and realist theories and apply them to their everyday world – whatever the timescale!

HOLMES' PARLOUR 221B

Waiting for Holmes to return, I was tucking into some of Mrs. Hudson's heavenly crumpets and tea. I had the intention of discussing that irritable yield stress thing that has so plagued the rheological world since Bingham [1] came up with the term. So many references to it exist. I took the trouble before visiting Holmes to search for "yield stress" on Google and came up with 591 000 hits, whilst a more specific search of "yield stress, rheology" gave 6130! While biting into my second crumpet, the door opened and in walked Holmes.

"Ah, Watson, my dear fellow, what brings you here today, and already on your second crumpet I see." said Holmes.
"Ah, Holmes, eh yes, I came to discuss the yield stress phenomenon with you." I blurted out.
"But how did you know it was my second crumpet, lucky guess I suppose." I said.
"Watson, I never guess, I deduce, and I can see from the level of flour on your plate and your sleeve that two of Mrs. Hudson's crumpets are required." barked Holmes. "Anyway, to business, the yield stress you say."

that nothing is happening to the sample at these low stresses. Indeed, as much is happening below the yield stress as there is above. If a sample will flow at high stresses then it will most certainly flow at low stresses – just very slowly. Creep I believe one calls it. Plenty of samples thought of as yield stress systems are simply very shear thinning systems, often with viscosity dropping by up to a million fold over the space of one decade of stress.

"Watson, I have to say, you are quite correct, but I fear that you are still applying a somewhat absolutist approach to your argument." Holmes said.

"But Holmes, any system capable of a relaxation mechanism cannot, by definition, be capable of a yield stress. There is always some method by which, at the molecular scale, movement and thereby flow can take place, assuming of course we are above absolute zero Kelvin." I said. "This is true for all materials."

I felt as though the weight of evidence against the yield stress was in my favour and that I may in fact win this debate.

"Watson, let me show you what a dangerous state we have got ourselves into here. Do you remember the paper in 1995 by Spaans and Williams [14]?" Holmes asked.

"Erm, no, not really Holmes, was there not some claim made that they had a system without a relaxation mechanism? I said.

"Well, not quite Watson, they used the Erying rate theory to try and imply that imposing a stress lowers any potential barrier to molecular movement in the direction of the stress, but raises the barrier in the opposite direction. Now, if this were the case, as our friend Barnes [3] pointed out what a marvellous discovery it would have been. They would have found the only substance in the universe that does not conform to the fundamentals of continuous creep!"

"I see, but Holmes, does it not seem that we are beginning to go round in circles with this debate now? After all have we not agreed that there is no fundamental yield stress. If one must refer to one then it should be in terms of an apparent yield stress." I said.

"Yes and no Watson, I was beginning to think that not only are we going round in circles, but that we may soon start bickering at each other like the most ignoble of politicians. I feel that we must begin to conclude our discussion and learn to accept, moving away from the semantics of the argument, that both camps are right and both camps are wrong!" stated Holmes.

"Both right and both wrong Holmes, you'll be telling me next that I'm Schrödingers cat!" I exclaimed.

"Watson, clarity, not hilarity is required at such a stage. I think you'll agree that we need to use our heads and our pragmatism in confronting this problem that really need not be a problem at all." said Holmes. "It basically comes down to what language we use and what we understand by that language. Evans in 1992 [15] said as much that the 'classical' definition used by Barnes and Walters in their 1985 paper [4] basically defines the yield stress out of existence, whereas if one chooses a practical approach defining the given strain sensitivity and time scale of the measurement one has basically defined the yield stress into existence." continued Holmes.

"Defining into or out of existence Holmes, really you exasperate me sometimes, what sort of conclusion am I supposed to draw from that?" I asked.

"Elementary my dear Watson, having been faced with incorrect or inaccurate definitions since its conception, the rheological world has raised its own storm in a tea cup. What they should be doing is leaving the esoteric semantics alone and concentrating on what they do best – rheology! They only need to carefully define their measurement parameters, not go making rash claims for the data out with the measurement range and they can happily use their yield stress values and principles. However, Watson, a word of caution to them, any application concerned with sedimentation would do well to heed the controversial arguments proposed as it is more than likely that creep forces will ultimately dominate." said Holmes. "Now let's finish up here with another cup of tea and a crumpet before going to the Strand Hotel where I have an appointment with a young woman concerning a red headed league. Will you join me Watson?"

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

ACKNOWLEDGEMENTS

Communicated on behalf of Dr. J.H. Watson by: Niall W.G. Young (Danisco A/S, Edwin Rahrs Vej 38, 8220 Braband, Denmark, niall.young@danisco.com) and Mats Larsson (ML Reologisk Mätteknik, Karl XII gata 10B. 22220 Lund Sweden, mats.x.larsson@telia.com).

REFERENCES

[1] Bingham EC and Green H: Paint, a plastic material and not a viscous liquid; the measurement of its mobility and yield value. Proc. Am. Soc. Test Matl. 20 (1920) 640-675.

[2] Bacon F: The advancement of learning (Original 1605), in Works, Volume 15 edited by Spedding J, Ellis RL and Heath DD, Cambridge MA (1863) 327.

[3] Barnes HA: The yield stress - a review or '$\pi\alpha\nu\tau\pi\rho\epsilon\iota$' - everything flows. J. Non-Newtonian Fluid Mech. 81 (1999) 133-178.

[4] Barnes HA and Walters K: The yield stress myth. Rheol. Acta 24 (1985) 323-326.

[5] Scott Blair GW: On the nature of "yield-value" Physics 4 (1933) 113-118.

[6] Watson JH: Decades of progress: The shifting boundaries of rheometers. Annual Transaction of the Nordic Rheology Society 9 (2001) 89-96.

[7] Dzuy NQ and Boger DV: Yield stress measurement for concentrated suspensions. J. Rheol. 27 (1983) 321-349.

[8] Bhattacharya S: Yield stress and time-dependent rheological properties of mango pulp." Journal of Food Science 64 (1999) 1029-1033.

[9] The Bible, King James Version. Judges, Chap.5, verse 5.

[10] Young NWG: The yield stress phenomenon and related issues - An industrial view. in Gums and Stabilisers for the Food Industry 11, edited by Williams PA and Phillips GO, Royal Society of Chemistry, London (2002) 226-234.

[11] Barnes HA. and Carnali JO: The vane-in-cup as a novel rheometer geometry for shear thinning and thixotropic materials, J. Rheol. 34 (1990) 841-866.

[12] Dzuy NQ and Boger DV: Direct yield stress measurement with the vane method. J. Rheol. 29 (1985) 335-347.

[13] James AE, Williams DJA and Williams PR: Direct measurement of static yield stress properties of cohesive suspensions. Rheol Acta 26 (1987) 437-446.

[14] Spaans RD and Williams MC: At last a true liquid-phase yield stress. J. Rheol. 39 (1995) 241-246.

[15] Evans ID: Letter to the Editor: On the nature of the yield stress. J. Rheol. 36 (1992) 1313-1316.

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