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EDITORIAL

Introduction: yield stress—or 100 years of rheology

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> "Accurately determine the meaning of words, and you will save world half misunderstandings"
> Rene Descartes

This issue of *Rheologica Acta* is devoted to the centenary of the first publication of the newly nascent science—rheology. This was a paper of E.C. Bingham (1916) "An investigation of the laws of plastic flow", *Bull US Bur Stand* 13**:**309–353.

Well, but what about earlier works demonstrating rheological effects—W. Weber (1841), F. Kohlrausch (1863), Lord Kelvin (1865) speaking about "viscosity of solids," J.K. Maxwell (1867), with the concept of relaxation, O.E. Meyer (1874), L Boltzmann (1874) with the principle of superposition, W. Voigt (1884), T. Schwedoff (1890) and some others?[1]

Yes, there were a lot of interesting observations and even general concepts, but a push was needed or a jump of some kind to give rise to numerous, significant, and continuous developments in a new consistent field.

Once, Mark Twain said: "How lucky Adam was. He knew when he said a good thing, nobody had said it before." This is true for science too.

It seems that such a jump (called the concept of the yield stress) was given by E. Bingham. It happened a century ago and—quite conventionally—it is thought as the birthday of rheology.

The frequency of using of "yield stress" and/or visco-plasticity is quite comparable with such fundamental terms as viscosity and elasticity. Thousands of publications concerned yielding of various materials for this century and the flood of studies related to this concept does not dry out, meaning that Bingham's concept continues to live and be in demand.

Meanwhile, one concept (yielding) was not enough for creating a new science. So, further steps were needed and they have been made. The second fundamental concept was *time effects*,[2] either as thixotropy or visco-elasticity. And finally, the concept of *finite deformations* and *non-linearity*[3] finalized the main structure components of rheology.

Now, the concept of yielding should be considered in the frames of the more general theoretical structures and included as a part of the other basic ideas making up the body of modern rheology.

Indeed, recent years have brought new results, novel ideas, and doubts. Is there "the" yield stress or something different? "The yield stress myth?"[4] or reality. All rheologists repeat as an incantation that "everything flows" (παντα ρει), but since the discovery of "viscosity bifurcation"[5] 15 years ago, most people now consider that the yield stress marks a limit between the existence of steady-state flows—above the yield stress—and the observation of continuously slowed down

[1] See Chapter "The Ground is prepared" in the book *Rheology: An Historical Perspective*, by R.I. Tanner and K. Walters, Elsevier, 1998.

[2] "God created Time, So That Things Would Not Happen At Once" *(Graffiti found at the wall of Caltech University rest room—cited after N.W. Tschoegl)*

[3] "It is difficult to make much headway in … rheology without an appreciation of the general importance of non-linearity", H.A. Barnes, J.F., Hutton, K.Walter, *An Introduction to rheology* (1989).

[4] H.A. Barnes, K. Waters, *Rheol. Acta* 24, 323 (1985).

[5] P. Coussot, Q.D. Nguyen, H.T. Huynh, D. Bonn, *J. Rheol.* 46, 573–589 (2002).

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flows. The statement "continuum mechanics is the ground for rheology" is cited in many textbooks, but the complex physical structure leading to the existence of most yield stress fluids also needs to be described and taken into account, since microstructural heterogeneities may make standard local descriptions inoperative.[6]

Concerning the definition of the yield stress, two situations have to be distinguished, since it either marks a transition from a liquid to a solid state or a transition from a solid to a liquid state. From the viscosity bifurcation concept, things now seem rather clear for the liquid to solid transition, although concluding that a flow is "steady" or "continuously slowed down" relies on an observation in a finite time; if this time of observation is large enough for any studied stress, an unambiguous jump takes place with drop in the terminal viscosity by several orders of magnitude at a definite—yield—stress.

A non-negligible ambiguity remains when studying the yield stress related to the long-term durability of the structure providing the solid-like behavior. The effect of the "life-time" processing the rupture is well known for many solid materials as well as for the multi-cycle loading of rubbers. This is also true to the solid-to-liquid transition at yielding. In this case, one should treat the behavior of a medium at yielding not in terms of the critical "yield" stress but as the dependence of the life-time on the applied stress without any "critical" point. Surely, this case is directly related to understanding the yielding as a thixotropic phenomenon described by the rate equation including terms which present kinetic processes of destroying and restoration of the inherent structure of the matter.

So, we can see that nature is richer for effects than described by the known Bingham equations of visco-plastic behavior and a lot of intermediate situations make the reality more interesting for study than simple mathematical models predict.

We suppose that all said above is sufficient to relate the centenary of rheology with Bingham's first paper. Noting this event, we tried to collect reviews, opinions, and research results of the most authoritative experts currently working in the fields of visco-plastic media. Their attitude to the problem under discussion can be different and even contradictory, and this is especially interesting and useful in search of answers which might be ambiguous. Their papers cover in particular the most up-to-date topics in the field: role of elasticity, wall slip, creep flows, and numerical modelling.

We are grateful to all our colleagues who agreed to participate in this project and presented their manuscripts for publication.

[6] V. Mansard, A. Colin, *Soft Matter* 8, 4025–4043 (2012).