Couette's Cell

Maurice Alfred Marie Couette (1858-1943)

A few years ago I walked into the office of a colleague, the soft matter chemist Susan Perkin, and noticed a strange device on her filing cabinet. The outside was a clear cylinder of Perspex. Inside was a clear drum with a handle on top. The space between the two was filled with glycerine. What was it, I asked. Sue took a syringe with food colouring and carefully injected a stream of blue liquid into the glycerin, carefully writing a letter C. She then turned the handle clockwise. As she did so the blue liquid began to spread, the letter blurring until it was unreadable. Then, without a word, Sue stopped and turned the handle the other way, and as she did so the blue dye gathered itself and the letter was magically restored. My jaw hit the floor; this was the closest thing to a time-machine I'd ever seen. But the device is no toy but a crucial instrument invented by Maurice Couette, one of the fathers of modern rheology, to measure viscosity.

Couette was born in Tours, on the banks of the Loire river, into a family of cotton merchants. He had an unconventional educational path, starting with a Catholic school in his hometown but then pursuing further studies in mathematics and physics in Tours, Poitiers and Angers where he began lecturing at the newly opened university. After a year's military service in Paris in 1880, he enrolled at the Sorbonne, while teaching at a number of Catholic schools, and began to study for a teaching diploma in physics. His studies put him into contact with the physicist Gabriel Lippmann (CK97, Sept 2015) and with the mathematician Joseph Boussineque. Couette began to look at the work of Claude-Louis Navier who in the 1820's had developed the first mathematical treatment of the "internal friction" (viscosity) of fluids.

Navier, of course, had not been the first to think about these problems. In the *Principia*, Isaac Newton had speculated on the motion of a fluid confined between two rotating cylindrical tubes – he predicted that the rate of fluid flow would depend on the distance away from the inner tube. Today we would think of this as "Newtonian" behaviour. A century and a half later, however, George Stokes imagined a similar set up and speculated that uncertain conditions – not least if the inner cylinder were rotated faster than the outer – that eddies would begin to develop, greatly affecting the observed viscosity. He also imagined an experiment to measure the speed of the fluid by observing "motes in the fluid" to check that fluid against the walls was stationary.

But all of this was quite theoretical and it was not until 1881 that Viennese physicist Max Margoles suggested using the concentric cylinder set-up as a way of measuring viscosity. The inner cylinder would hang from a torsion wire while the second would be rotated around it. The viscosity could then be related back to the degree to which the wire twisted.

In Paris Couette began to test Navier's and Stokes equations. On the one hand, he allowed water to flow through glass tubes, developing a careful mathematical treatment to correct for end effects. Couette showed for the first time that, as Navier and Stokes had predicted, the fluid in contact with the walls was stationary.

But Couette also developed Margoles's idea, though he brought it to a very high level of sophistication. The device was constructed by the Parisian instrument maker Eugène Ducretet with exquisite precision: the radii of the inner and outer cylinders were reported to be 14.6395 and 14.3942 cms respectively. The outer cylinder was rotated using a pulley while the torque on the inner cylinder could be measured either using the torsion wire, or by using an Atwood's machine, in which the force could be counterbalanced by a weight passed over a pulley.

Unbeknownst to Couette, a young English physicist Arnulph Mallock (1851-1933), a laboratory assistant of Lord Rayleigh's, developed an apparatus along similar lines, but with replaceable cylinders of different lengths. The apparatus worked beautifully and Lord Kelvin, who saw it in 1895 insisted on dipping a glass rod into the gap between the two cylinders and was rewarded by a satisfying increase in the torque on the inner cylinder as the resulting turbulence rapidly increased the observed viscosity.

But Couette could operate across a wider range of spinning speeds, and in the absence of any disturbance showed that the apparatus operated in two different regimes. A slow speeds the measured viscosity was constant as predicted by Newton and Navier; but at some critical speed the behaviour suddenly changed, the viscosity increasing with rotation rate, marking the transition to turbulent flow. Making meticulous correction for imperfections in his apparatus, Couette made measurements for a variety of fluids – his value for the viscosity of air was within one percent of the value determined half a century later. But perhaps tragically, because his cylinders were made of steel, he never saw the spectacular dynamics that appeared in the turbulent regime. Working in glass 30 years later, Geoffrey Taylor visualised (and photographed) the intricate patterns of wavy or even spiral eddies in the fluid by injecting ink (rather than "motes") between the spinning tubes. Remarkably, however Couette's invention may have found a new lease on life. A recent paper the Journal of Food Engineering describes a method in which soy protein is not only denatured by the shear forces between the spinning drums, but it also aligns the molecules into fibrils. The result is a solid slab resembling a steak. It's not quite as exciting as a time machine, but it could widen the textural options for hungry vegetarians.

Reference
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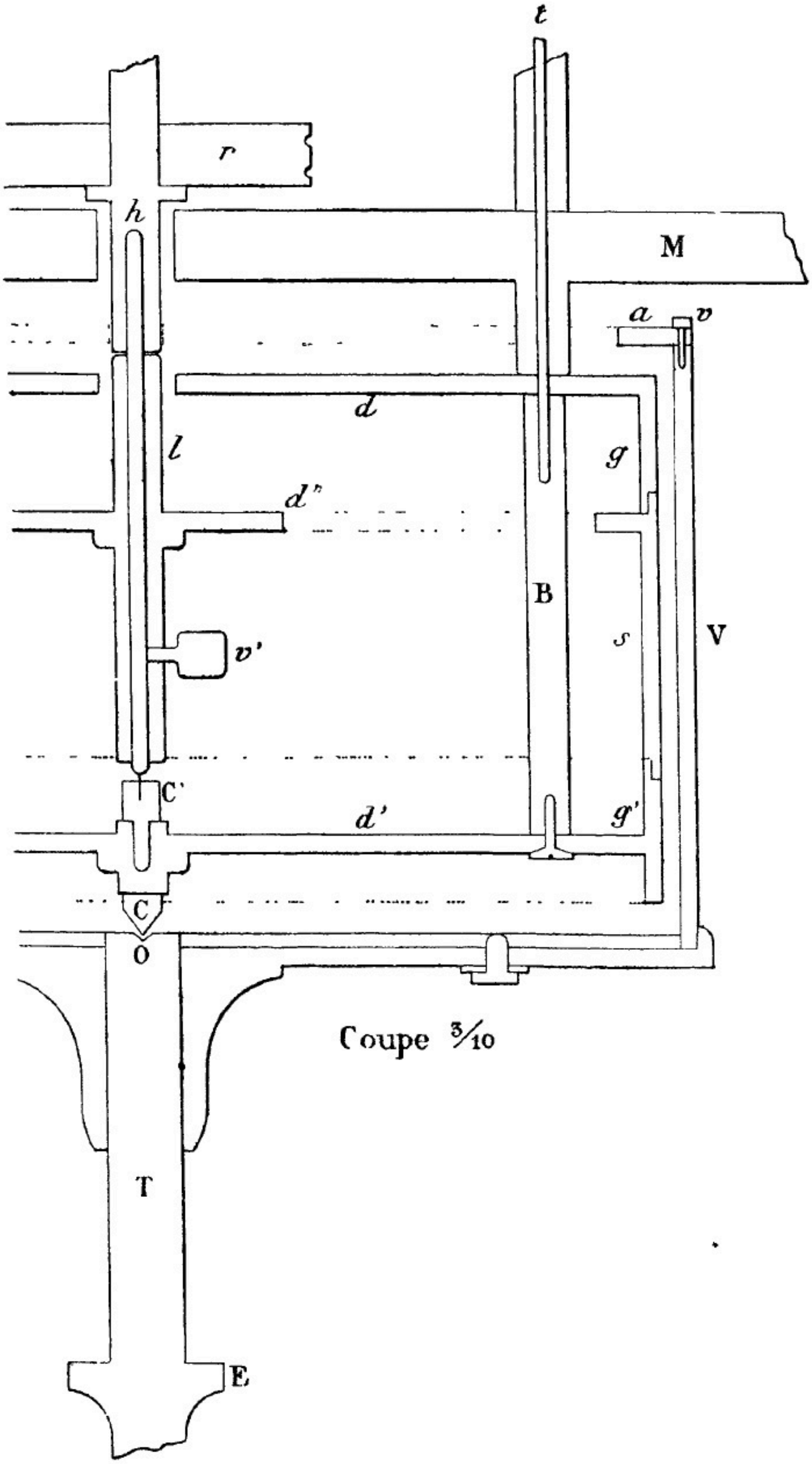

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