Fluid flow

Turbulence splits polymers

from A. Keller and J. A. Odell

EVEN minute quantities of long-chain molecules can dramatically influence the flow properties of liquids to which they are added, an effect that has many practical applications. However, limits are set on the usefulness and range of applications of polymer additives by the fact that the longest polymer chains are more effective but are also most likely to break during flow. Horn and Merrill[1] report on page 140 of this issue that such degradation of long flexible polymers subjected to turbulent flow conditions occurs by breakage at the midpoint of the molecules. Such apparently simple observations of degradation are also providing an insight into the molecular processes underlying many problems in fluid transport.

The countless examples of the use of polymers to modify fluid flow range from thixotropic ('non-drip') paints to engine oil viscosity enhancers. The energy required to pump liquids in turbulent flow can be reduced by up to 70 per cent ('drag-reduction') by the presence of a few parts per million of flexible long-chain molecules[2]; this has found practical applications in pipelines, heating systems and sewage disposal. Recently polymeric aircraft fuel additives have been developed to prevent fuel from 'misting', thereby dramatically reducing the risk of fire in the event of accident[3].

The scientific approach to these effects has mostly been that of formal macroscopic hydrodynamics. Explanations on a molecular level have been proposed but are largely untested. A common hypothesis is that the effects are associated with the stretching out of flexible long-chain molecules in the course of flow. Since this process absorbs energy it could suppress droplet formation in misting, or defuse the nucleation of critical vortices during turbulent flow.

The earliest predecessors of Horn and Merrill's observation of midpoint scission of polymer molecules concern DNA[4-6], which is not a highly flexible chain, but a rather rigid worm-like entity. Clearly a rigid rod-like molecule in any flow field will experience the greatest force at its centre, so that midpoint scission can be anticipated. But the more common flexible molecule chains are initially present as a tangle (random coil) and their scission would be expected to occur randomly along the chain. Only if the molecule is first straightened out can it be expected to behave as a rod and break at midpoint.

The systematic achievement of full stretching of chains through flow is by no means trivial, as conventional simple shear flows (such as laminar flow in a capillary or between rotating concentric cylinders) merely distort the coil but do not straighten the chain. Instead, it is necessary to use special elongational flow systems in which there is a uniformly accelerating flow of very high velocity gradient (strain rate). Our own studies[7] have shown that at a critical strain rate, which depends upon molecular length, the molecules undergo a sharp transition from the random coil to the fully extended state. At a higher and fixed strain rate, the increased force on the stretched-out molecules ruptures them at midpoint. The strain rate required to produce scission is proportional to the square of the length of the chain. This is predictable from the stresses arising in a stretched-out chain subjected to extensional flow. The deduced rupture strength of the chain is comparable to the strength of a covalent bond in the backbone.

This close correspondence between the fracture behaviour of coiled polymers under these model flow conditions and that of a straight molecule provides strong evidence that the coiled chains have been fully stretched out. Merrill and Horn, having corroborated these results and extended them to laminar flow through constrictions[8], have now transferred the ideas and methodology to the less well defined, but perhaps practically more important, condition of turbulent flow.

It has been hypothesized that in turbulent flows elongational flow fields prevail locally in vortices, producing local chain extension[9]. This cannot be observed directly on the microscale within the otherwise inhomogeneous turbulent flow, as could be done in the laminar model flow systems. Yet, as now reported, the unique effect of such flow and extension in the form of midpoint scission is observed[8]. By analogy to the experiments with model flow systems, Horn and Merrill infer that the chains must indeed have been stretched out by the turbulent flow field.

With the behaviour of macromolecules in turbulent flow now becoming accessible to experiment, we have reached a firm starting point for a molecular understanding of the intriguing and important flow-modifying effect of macromolecules and its consequences for fluid transport. □

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Molecular neurobiology

And now the sodium channel

from Charles F. Stevens

THE cloning and sequencing of the cDNA of the electric eel's sodium channel, described by M. Noda and seventeen colleagues on page 121 of this issue[1], reaffims that S. Numa's laboratory at Kyoto University is the preeminent factory for cloning peptides and proteins of importance to neural function. More importantly, it is a key step in revealing the molecular basis of the electrical excitability of neural tissue and muscle.

What is the sodium channel and why is it important to clone and sequence its DNA? Channels — as the proteins responsible for brain electrical activity are called — fall into into two nearly mutually exclusive classes: ligand-gated and voltage-gated. The former, when bound to by their ligands (specific neurotransmitter molecules) open to permit ion flux across the neuronal membrane. By contrast voltage-gated channels open and close in response to the voltage difference between the inside and outside of the neuron. The archetypal ligand-gated channel is the acetylcholine receptor (AChR). Numa's laboratory was the first to clone and sequence all four subunits of AChR, and is now first to clone and sequence an example of a voltage-gated channel. In picking the sodium channel, they chose the membrance protein responsible for the nerve impulse.

Not only do AChR and sodium channels fall into different physiological classes, but they also belong to different structural classes. Whereas the AChR is a pentameric protein composed of structurally similar subunits, the picture of the sodium channel that emerges from the cDNA sequence of Noda *et al.* is of structurally similar domains within a single protein. The sodium channel of the electric eel is thought to consist of a single protein of >200,000 molecular mass. The cDNA sequence of this protein shows it to contain four domains, each of which is 250–300 amino acids in length and about 50 per cent homologous with the other three domains. Each domain has a similar overall structure with 6 identifiable subregions; two of these subregions are hydrophobic and presumably membrane-spanning, two are negatively charged, one has a large net positive charge, and one has no net charge.