Making Oil Flow Faster for Cheaper

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One of the most ubiquitous features of modern industrial society around us is the large-scale transport of raw materials and finished goods from one part of the world to the other. Oil, gas and other petroleum products form the bedrock of an industrial society and hence, their efficient transportation is of the utmost importance for both economic and social reasons. This importance is clearly illustrated by the fact that more than 35,000 km long pipelines are devoted to transporting, both raw and processed, petroleum products in India. Maintaining and operating these pipelines, and the associated infrastructure, thus amount to a significant portion of the country's gross domestic product. With the consumption of crude oil projected to keep growing in the coming years, reducing the cost of pumping involved is thus, an urgent need.

One method suggested to achieve this has been to add *polymer molecules* to the oil pipeline. *'Polymers'* are composed of thousands of repeated sub-units, and form the basis of the myriad things we see around us, most notably plastics. When such polymers are added, even in tiny amounts to a pipeline the resistance to pumping, the 'drag', drops remarkably, phenomenon dubbed as ***'Drag Reduction'***. This has been observed several times, although the physical process of how this happens lacks a complete explanation to-date. Even though it was first discovered in the 1950s, the wide applicability of this method has been hampered by a lack of understanding of the physical phenomenon involved. This makes achieving control and to repeat difficult, both of which are crucial for industrial applications. Since direct approaches to answer this puzzling question have failed over the years, we aim to answer the question of how the drag-reduced state is set-up through

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our research. But before beginning our research, we found, it is important to take a detour and examine the question of why it is so hard to pump oil over large distances.

A common observation which is made by every child, but the most famous first recording is in Leonardo da Vinci's sketches, is that as any fluid, water or oil included, when pumped faster and faster, it starts to develop random swirls and patterns and flows in a disordered fashion. This is the famous state of ***turbulence,*** during which aeroplane captains don't tire of warning you to wear your seatbelts. The same phenomenon, however, is encountered in oil pipelines when the flow rate at which oil is being pumped is large enough. When at small flow rates, an ordinary fluid, like oil or water, flows in an orderly fashion and hence, can be pumped effectively at relatively little energy cost. But when pumped fast enough, which is a requirement for transport over long distances, the extra swirls and disorder encountered cause additional friction in the pipe and the efficiency of pumping drastically reduces. A simple thought then presents itself, can the disordered state be avoided, or failing that the disorder minimized? If one could do that, one could maintain a larger efficiency of pumping. This is where the aforementioned polymer molecules, and our novel research work, come into this story.

We tackled the problem by studying a mathematical model that represents the presence of the polymer in a coarse-grained sense. This model provides an effective 'memory' to the oil; that is with polymers added the oil is a material that behaves both as a solid and a liquid! It has long been postulated that this unique behaviour is responsible for the drag-reduction mentioned earlier, although how has remained elusive. Our analysis, of this model, has shown that the presence of polymers can lead to novel patterns in the flowing oil in the pipe in sharp contrast to what was believed so far in the literature. We showed that these self-excited patterns are completely distinct from those that are found in ordinary oil at large flow rates, i.e. ordinary turbulence. These new patterns result from a subtle interplay of the fluid-like property of the oil dynamically interacting with the solid-like memory provided by the added-polymer molecules. We went a step further and quantitatively characterized the material properties at which these new patterns should be observed in the laboratory. In fact, these parameter values matched very closely with those reported by an experimental group a few years earlier who were studying the same problem in the laboratory. Their observations had remained a mystery so far. But wait, how did we discover these new patterns, you ask? That was thorough, and hence unfailing, mathematical analysis. This analysis gives us, for the first time, the knowledge to predict, quantitatively, what type of flow will be achieved in the oil pipeline. This was the crucial missing ingredient which had so-far prevented a large scale adoption of this highly promising technique. Our research directly overcomes this hurdle.

By demonstrating this new pathway, which was hitherto completely unexpected in the literature, these results overturn some widely held beliefs. It was expected that the swirling state only changes a tiny bit upon the addition of the drag-reducing agent. This idea was so entrenched that most designs that tried to incorporate this effect assumed this and hence ended up being severely inefficient. Our results clearly demonstrate the contrary and hence for the first time open up an avenue to achieve, and hence control, the new random state. And you guessed it right - this state is expected to have all the right properties thus enabling efficient design.

But like all good stories, this one has only reached the middle and a lot of work still needs to be done. Mathematics can only take you so=far, and we are now planning to carry out our research by using computers to analyse the new swirling state itself. This would bring us one step closer to the Holy Grail - actually designing cost-efficient pipelines by using the ideas we discovered. One would hope that the end moral of this story would be one all research stories aspire to - combining scientific knowledge to solve pressing societal needs.