

## Drag Reduction Possible In The Transition Region

# High Viscosity Crude Drag Reduction

### LIQUIDS PIPELINE REPORT

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Drag reducing agents, or DRAs, can produce substantial decreases of the frictional pressure drop of fluids in turbulent flow when injected at concentrations of just a few parts per million.

The phenomenon of turbulent flow drag reduction by polymer additives was first discovered by B.A. Toms in 1948. Research interest in aqueous and hydrocarbon fluids intensified in the 1960s and 1970s. One of the earliest commercial applications was the use of water-soluble polymers in fire-fighting equipment. A summary of the research progress in drag reduction is given by Virk. The first commercial use of a hydrocarbon-based DRA was drag reduction of the Trans Alaska Pipeline.

DRAs are effective only when the flow is turbulent. When a DRA is dissolved in a solvent in laminar flow, the pressure drop is either the same as the pure solvent at the same flow rate, or slightly higher due to

the very slight increase in the solution viscosity due to the presence of the polymer.

Nearly all the data reported to date in the literature are for solvents with a fairly low viscosity (less than 20 cp) and high Reynolds numbers. For example, the Reynolds Number in the Trans Alaska Pipeline is greater than 500,000. This article discusses a series of experiments conducted in a high viscosity crude (48 cp) over a range of Reynolds numbers of 1,790 to 3,000.

The flow is laminar below a Reynolds Number of 2,100, and no drag reduction occurs. As discussed by Schlichting and Hinze, the flow is transitional from Reynolds numbers of 2,100 to 4,000 and only partly turbulent. In the transition region, the fluid in the pipe travels along in alternating slugs of fluid in laminar and turbulent flow. As the Reynolds Number increases, an increasing percentage of the fluid is in turbulent flow at any given time. At a Reynolds Number of approximately 4,000 under normal pipeline conditions, all the fluid is in turbulent flow.

With highly effective DRAs, effective drag reduction can occur as soon as the transition to turbulent flow begins and drag reduction is not inhibited by high solvent viscosity.

**Experimental equipment.** The experiments were performed with a 2-in. by 200 ft long circulating test loop (Fig. 1). The crude oil to be tested was held in a 3,000-gal. feed tank that could be either heated

with steam or cooled with a water-glycol chiller. A 10-hp centrifugal pump with PID flow rate control circulated the crude. Fluid velocity was accurately controlled over a range of 3 to 10 fps. Fluid temperature could be trimmed to within 0.2° F of the desired operating temperature with an air heat exchanger.

The test section consisted of a 100-ft run of pipe, a 180° bend, and another 100-ft straight run that returned to tankage. Three differential pressure transducers (DP cell) were spaced on 28-ft centers along each straight run, with the pressure taps located 25 ft apart. The cumulative pressure drop was measured over the full length of the test section and over the first straight run of pipe. The flow rate, fluid temperature, and differential pressure cell data were taken, analyzed, and stored by a Hewlett-Packard 85 personal computer.

DRA was injected 7 ft upstream of the first pressure tap by a hydraulic cylinder. The hydrocarbon-based DRA used in this study was FLO™ Pipeline Booster, a proprietary product of ChemLink Petroleum Inc. FLO was pre-diluted with kerosene to a polymer concentration of 0.15%. At this concentration, dissolution of the product is nearly instantaneous. The final concentration of the polymer DRA in the crude oil was 5 ppm by weight.

**Data reduction.** Drag reduction data can be easily visualized when plotted on Miller formula coordinated of  $1 / \sqrt{f}$  1.8 log (Re). The turbulent flow baseline is given by the Miller formula:

$$1 / \sqrt{f} 1.8 \log (Re) - 1.53$$

where  $f$  is the Moody friction factor. The advantage of this plot is that the turbulent flow baseline is a straight line over a wide range of Reynolds numbers. Previous experiments have shown that the 2-in. loop baseline always closely matches the Miller formula when the flow is fully turbulent at Reynolds number greater than 4,000. On these plots, a reduction in drag is represented as a higher value of  $1 / \sqrt{f}$ . The data can also be examined as a percentage decrease in pressure drop at a fixed flow rate. Percent drag reduction is defined as:

$$\%DR = \frac{\Delta P^O - \Delta P^{DR}}{\Delta P^O}$$

when  $\Delta P^O$  is the baseline pressure drop and  $\Delta P^{DR}$  is the pressure drop with the drag reducer at the same flow rate.

**Results.** Flow rate and pressure drop measurements were made in Alaskan

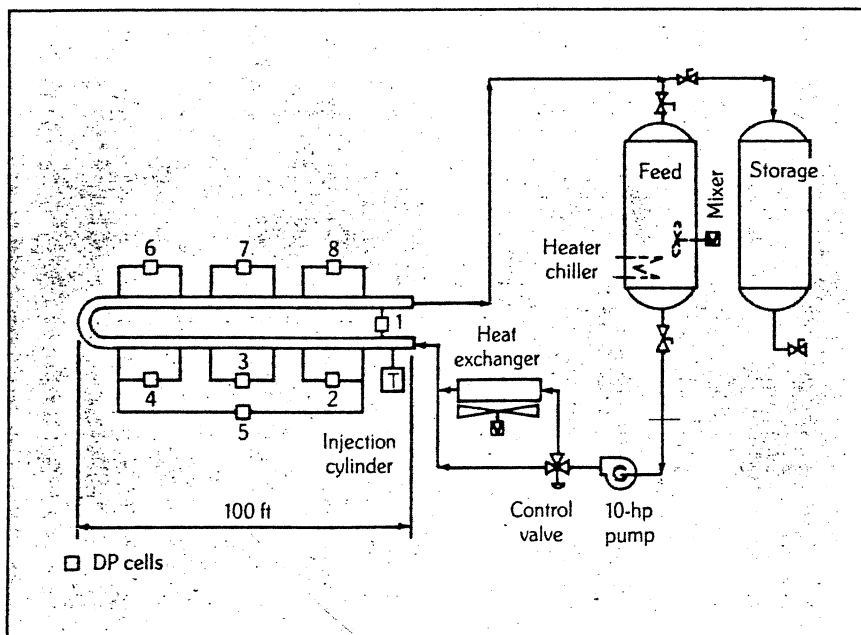


Fig. 1. DRA Test Loop, 2-in. by 200 ft

North Slope crude oil at a fluid temperature of 57° F. The crude oil viscosity was measured as 48 centipoise and the density was approximately 25° API. Measurements were made at 10 fluid velocities ranging from 6 fps to 10 fps.

A plot of percentage drag reduction (measured at DP cell 3 where the FLO was fully dissolved) vs Reynolds Number is shown in Fig. 2. There was no drag reduction at the lowest three velocities as the flow was completely laminar. At a Reynolds Number of 2,370, just into the transition region, a 1% drag reduction was observed. As the Reynolds Number increases to 2,960, percentage drag reduction increased 25% to 27%.

The same data are shown replotted on Miller coordinates in Fig. 3. The theoretical lines for laminar and turbulent flow are also plotted. Focusing attention on the baseline data taken with DRA, the  $1/\sqrt{f}$  values for the first four Reynolds numbers nearly perfectly match the theoretical laminar flow line. At larger Reynolds numbers, farther into the transition region where an increasing fraction of the fluid is in turbulent flow, the values of  $1/\sqrt{f}$  decrease towards the fully turbulent baseline given by the Miller formula. However, even at the highest Reynolds Number of 2,960 the flow is not completely turbulent as evident from the value of  $1/\sqrt{f}$  above that of the Miller formula.

Data for crude with 5 ppm drag reducer are also plotted on Fig. 3. These friction factors were calculated using the average pressure gradient from DP cells 3, 4, and 6 through 8. The  $1/\sqrt{f}$  values for the lowest three Reynolds numbers are actually slightly lower than the corresponding baseline values since the flow is laminar and the crude viscosity is slightly increased due to the presence of the polymer. This is also reflected in the small negative percentage drag reduction values in Fig. 2 at these velocities. Above a Reynolds Number of 2,190, as velocity increases the difference between the  $1/\sqrt{f}$  values of the baseline condition and the drag reduced flow increases.

When the data are plotted against the baseline condition as in Fig. 3, the reason for the low drag reduction at the low Reynolds numbers is clear: the flow is not completely turbulent. In the transition region, only the portion of the fluid that is in turbulent flow is affected by the drag reducer. Only the fraction of the total pressure drop that is due to the turbulent flow can be reduced, leading to low percentage drag reduction values.

**Conclusions.** The experiments show that drag reduction is indeed possible in fluids of high viscosity. The results also prove that a high Reynolds Number is not a requirement for effective drag reduction, which can occur in flow systems that are in fact only partly turbulent. Any fluid in turbulent flow is a viable candidate for drag reducing additives.

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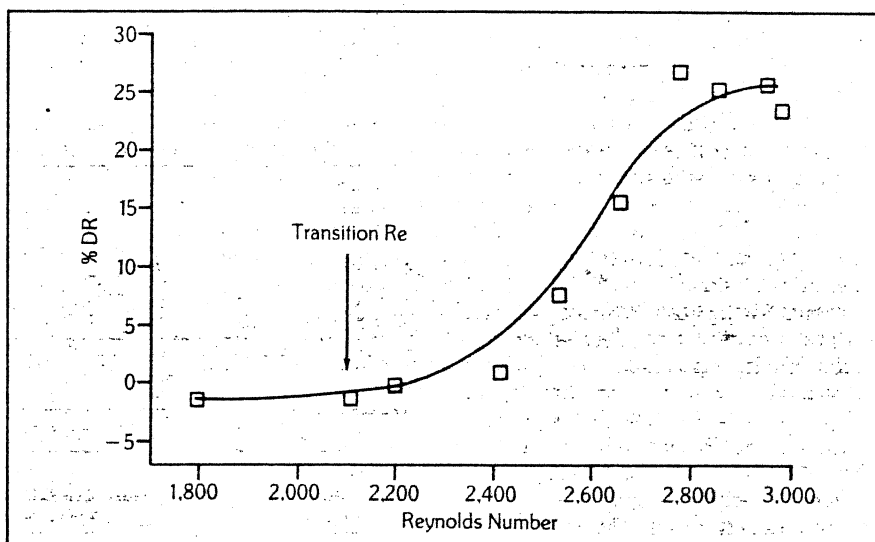


Fig. 2. % Drag Reduction vs Reynolds Number

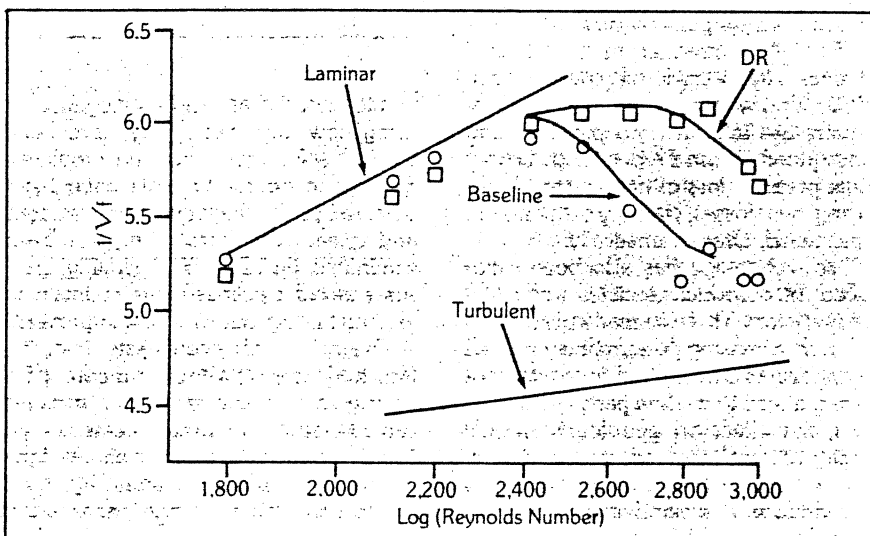


Fig. 3. Miller Plot of DR in 48 cp Crude