Drag reduction in turbulent crude oil pipelines using a new chemical solvent

A. R. Mansour
Chemical Engineering Department, Yarmouk University, Irbid, Jordan

O. Swaiti, T. Aldoss, M. Issa
Mechanical Engineering Department, Yarmouk University, Irbid, Jordan

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Pilot-scale experiments have been conducted to reduce drag in pipelines carrying crude oil using a new chemical additive. The effects of pipe diameter and crude oil flow rate on drag reduction rate have been studied in 1″, 2″, 3″, and 4″ pipes. The effect of additive concentration on drag reduction was also investigated, and it was found that a 9-ppm concentration of the chemical solvent is optimum for the studied system. A maximum drag reduction of 63% has been achieved when 9 ppm of the solvent was added to the 4″ pipe.

Keywords: drag reduction; crude oil; chemical solvent; pumping cost

Introduction

The process of reducing skin friction in pipes by the addition of a drag-reducing agent is known to scientists and engineers. Its importance lies in the capability of maximizing flow rate of pumping fluids inside pipes or minimizing the pumping costs. Many papers have been published in this area,[1–9] but few of them used large-size pipes in their experiments. The objective of this work is to quantify the drag reduction that may be obtained by introducing a new chemical additive into large-scale pipes carrying crude oil.

Experimental

Equipment

Figure 1 shows the model used in the experiment. It consists of (1) centrifugal pump, (2) four carbon steel pipes (1″, 2″, 3″, and 4″ diameter), (3) mercury manometer, (4) thermometer, (5) flowmeter, and (6) 1-m^3 storage tank.

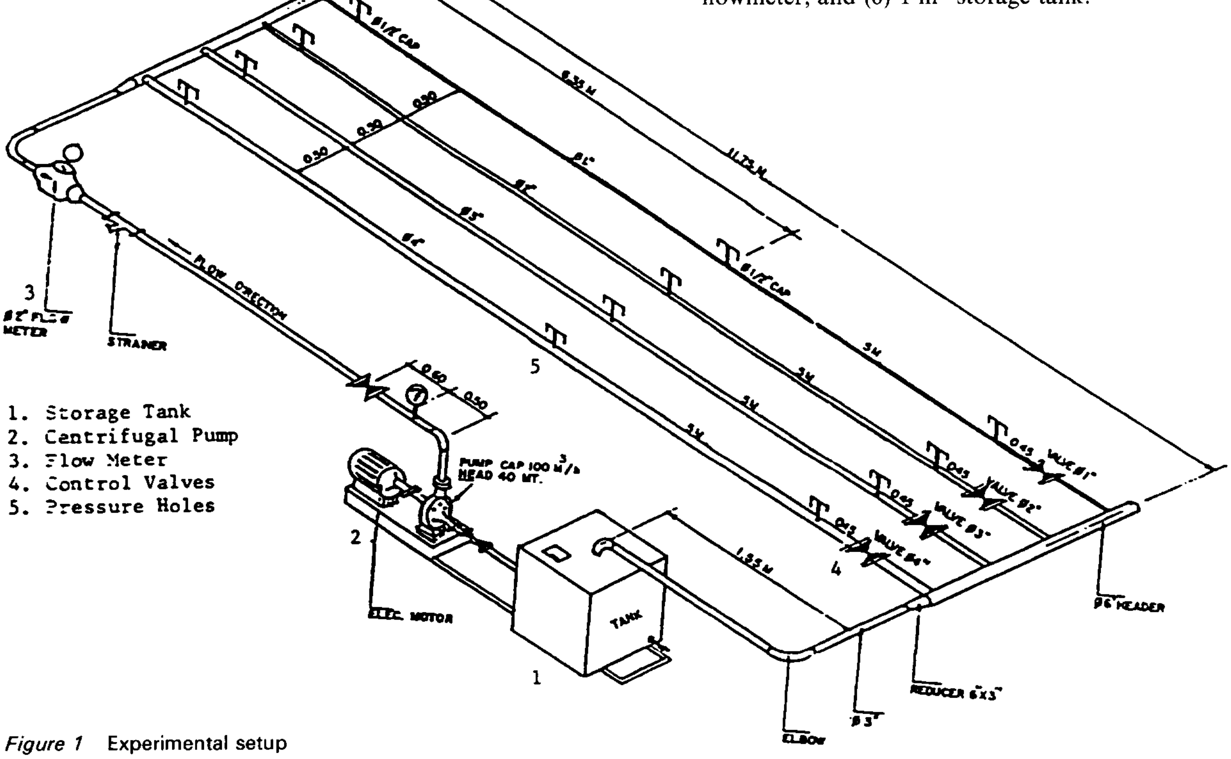

Figure 1 Experimental setup

Materials

The materials used are Iraqi and Saudi crude oils and a chemical solvent called GEM (see Appendix A).

Experimental procedure

A set of experiments has been carried out to investigate the effect of GEM chemical solvent on the drag reduction of a turbulent flowing crude oil in pipes of different diameters.

Crude oil was pumped from a storage tank (Figure 1) via a centrifugal pump. Before any chemical solvent was added, the crude oil was pumped in each pipe of specified diameter separately from the other pipes assembled in the same loop, as shown in Figure 1. The corresponding flow rate is measured by the installed flowmeter. For each pipe pressure drops between points of 5 m apart are recorded by the associated multitube manometer. Readings were recorded every 20 min. The corresponding temperatures were determined by putting mercury thermometers in each pipe through special holes with proper fittings.

The chemical solvent was added by a syringe in known quantities to the crude oil tank of known volume. The flow rate was varied by timing the flowmeter for pure crude oil. After the solvent was added, thus specifying its concentration in the flowing oil, the oil was circulated in one pipe and the others were isolated from the loop by closing the relevant valves. Starting with a concentration of 3 ppm up to 20 ppm, crude oil for each GEM concentration was pumped consecutively in the four different pipes.

In the range of prespecified concentration, measurements for the four pipes at different flow rates were taken. Measurements were taken more than once to secure repeatability of the experimental results.

Results and discussion

Comparison between experimental and theoretical results

In order to check the accuracy and certainty of the experimental procedure, a set of experimental results for the 4″ commercial pipe with relative roughness of 0.00015 were compared with the theoretical data presented in the Moody chart. Figure 2 shows that the experimental results obtained in this study are within the acceptable limits of accuracy.

Results for Iraqi crude oil

Figures 3–6 show the variation of drag reduction (D.R.) percentage with Reynolds number for Iraqi crude oil flowing into the 1″, 2″, 3″, and 4″ pipes, respectively, for a solvent concentration ranging between 3 and 20 ppm.

Effect of solvent concentration. Figures 3–6 show that D.R. increases as solvent concentration increases for all pipe sizes. It

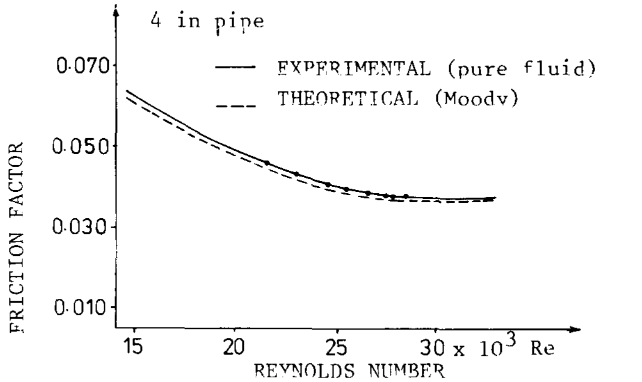

Figure 2 Comparison of experimental results with Moody chart for pure crude oil

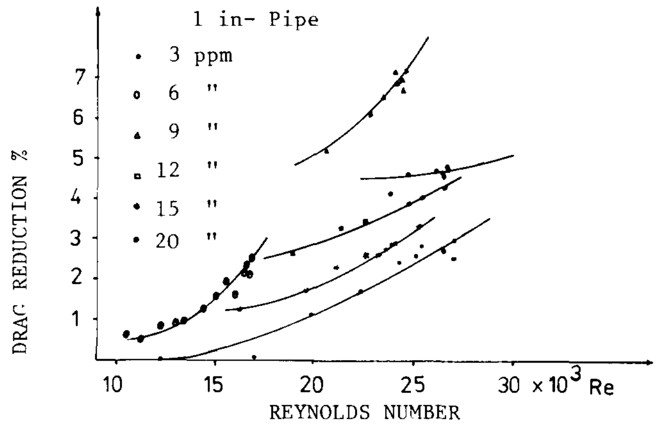

Figure 3 Drag reduction results for 1″ pipe

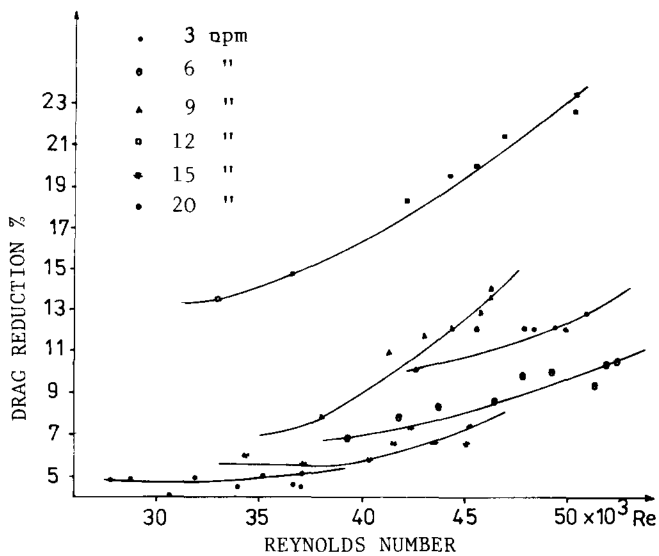

Figure 4 Drag reduction results for 2″ pipe

Notation

D	Pipe diameter
D.R.%	Drag reduction percentage
f	Fanning friction factor
ppm	Part per million (on weight basis)
Re	Reynolds number (dimensionless)
u	Flow velocity
u^*	Friction velocity
Subscripts	
f	Fluid (crude oil)
s	Solvent-crude oil mixture

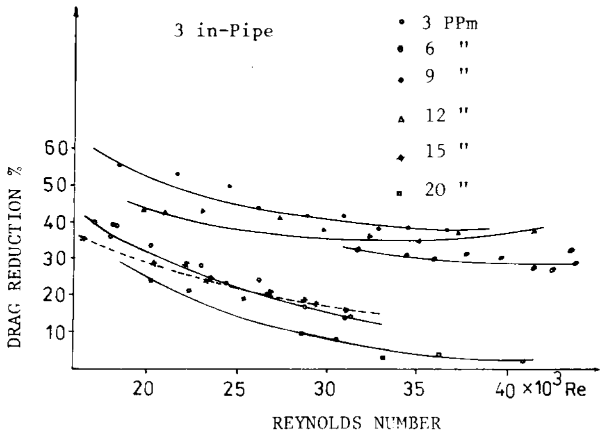

Figure 5 Drag reduction results for 3″ pipe

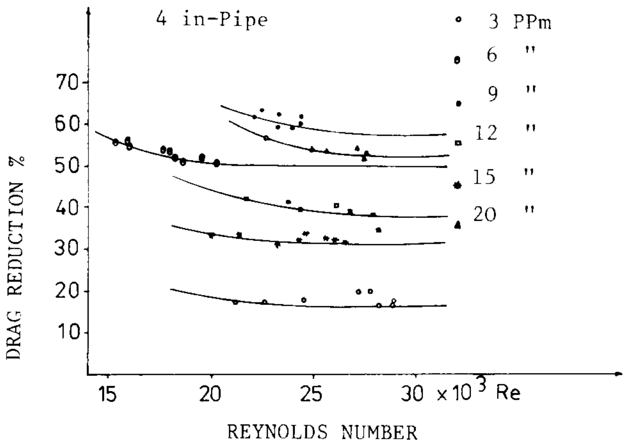

Figure 6 Drag reduction results for 4″ pipe

is obvious from Figure 7 that for all pipe sizes the D.R. increases as solvent concentration increases till it reaches a maximum value, after which the D.R. starts to decrease. This agrees with all previous works reviewed in Refs. 1 and 2. This phenomenon can be explained by the elastic-sublayer model theory of Virk,[2] where this sublayer originates at an onset (the onset in our case is 3 ppm) and then starts to grow with increasing solvent concentration until it eventually occupies the entire pipe cross section, where the maximum D.R. is achieved (in our case it is 9 ppm for the 3″ and 4″ pipes). After the maximum D.R. value is reached, additional quantities of solvent seem to change the properties of the elastic sublayer in the reverse sense. This phenomenon is reported by Hoyt[1] and Virk.[2]

The decrease of the D.R. amount after a certain concentration of solvent may be interpreted by the mixture tendency to behave as a non-Newtonian fluid, which causes higher friction or less D.R.

Effect of pipe diameter. Figure 8 shows that D.R. percentage increases as pipe diameter increases for different turbulent Re values. Therefore a maximum D.R. (63%) is obtained in the 4″ pipe. This amount of D.R. seems to be promising for practical applications.

These findings agree with the works of Berman,[4–8] who found that in a larger pipe, where the persistence time of the strain field is higher, D.R. increased, compared with a smaller pipe size. Berman[8] reported that this phenomenon can be interpreted by turbulent or molecular interactions as follows: Drag reduction can be increased when pipe diameter is increased if the persistence time of the large eddies that is proportional to D/u^* is important. This persistence time is related to the length of time the molecules are stretched in the relatively rotation-free, high-strain-rate areas of turbulent flow, and the mean distance between two molecules is less than the size of an elongated molecule.

Laufer and Narayanan[9] showed that Newtonian fluids give turbulent bursting time proportional to D/u, and Berman[8] reported that his observations suggest that the bursting time would scale with D/u^*. This explains why D.R. will be higher for larger pipe diameters.

Results for Saudi crude oil

Figures 9–12 show the variation D.R. with Re number for Saudi crude oil flowing into the four different pipes considered in this study for various solvent concentrations.

Effect of solvent concentration. Figure 13 shows that the optimum concentration at which maximum D.R. is achieved for the four pipes is 10 ppm.

Effect of pipe diameter. Figure 14 shows that D.R. increases with pipe diameter, and that a maximum D.R. of 50% occurs in the

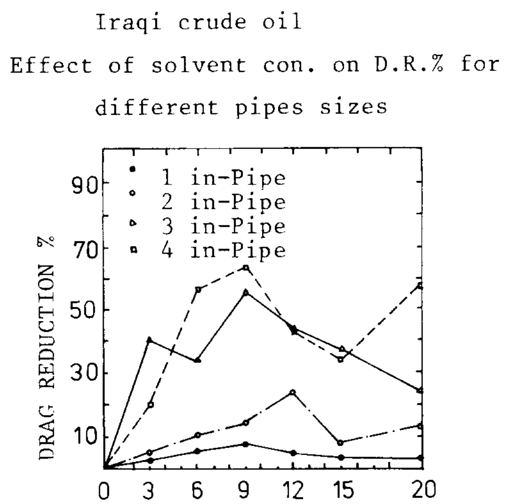

Figure 7 Solvent concentration (ppm)

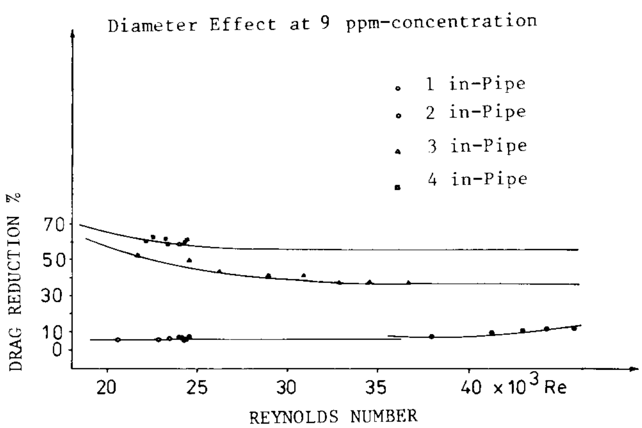

Figure 8 Effect of pipe diameter on drag reduction

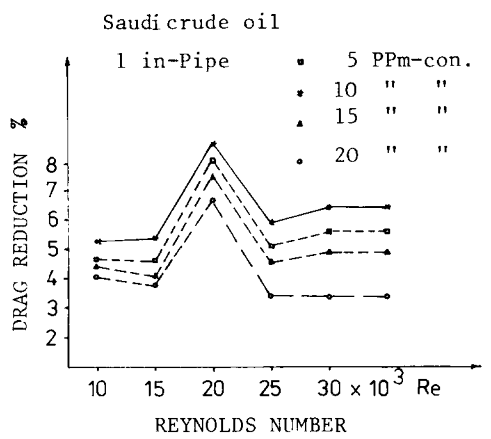

Figure 9 Drag reduction results for 1″ pipe

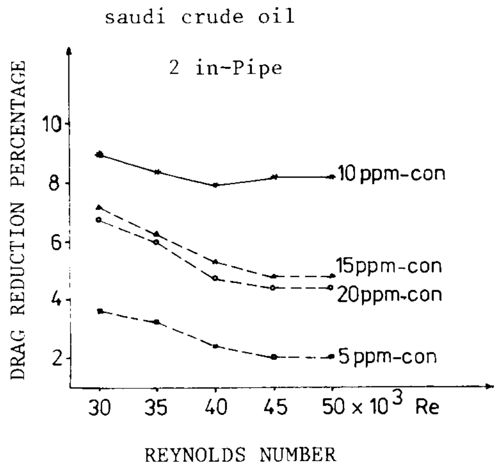

Figure 10 Drag reduction results for 2″ pipe

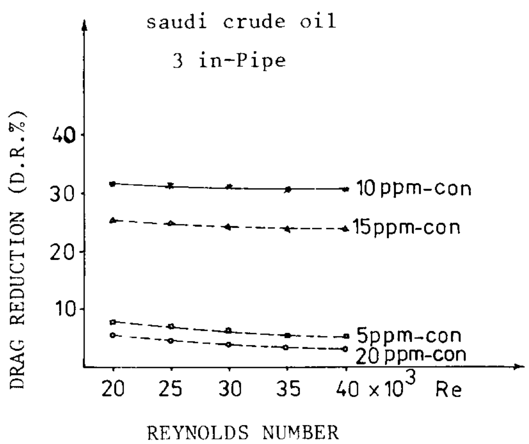

Figure 11 Drag reduction results for 3″ pipe

4″ pipe. These findings are consistent with those obtained for Iraqi crude oil.

Effects of crude oil flow rate

Figures 3 and 4 show, for small size pipes (1″ and 2″ pipes), as reported by Hoyt,[1] Virk,[2] and Mansour,[3] that the D.R. rate increases with Re (flow rate) for fixed pipe diameter.

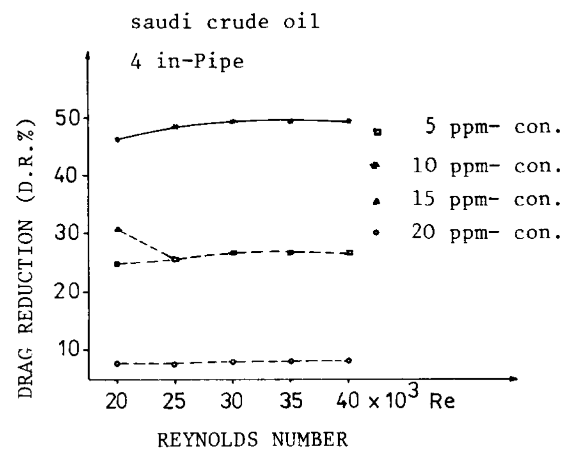

Figure 12 Drag reduction results for 4″ pipe

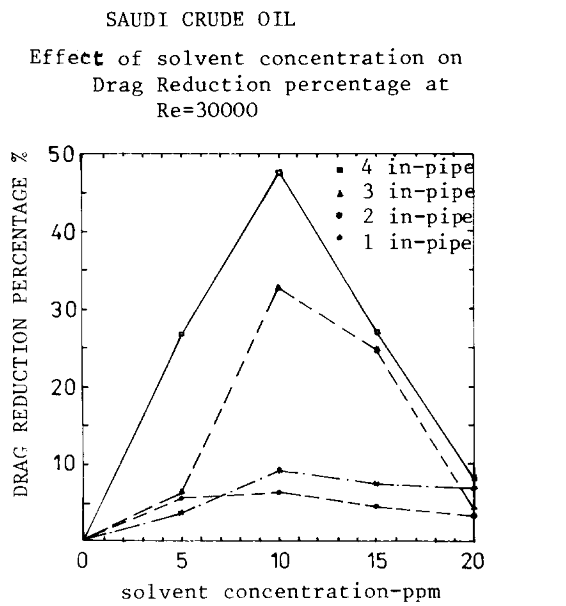

Figure 13 Solvent concentration (ppm)

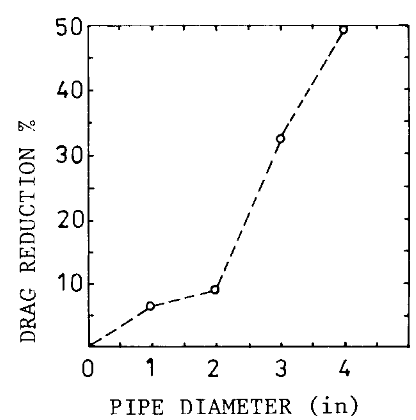

Figure 14 The effect of diameter on drag reduction percentage at constant Re (=30,000) and constant GEM solvent concentration (10 ppm)

This behavior agrees with Berman's works,[4–8] in which he reported that an increase in Re leads to an increase in the strain rate and a decrease in the time scale. Then the elongation reaches a constant level for a given solution and pipe diameter when no other limits are present.

In this case the polymer tends to lower the slope of the Fanning friction factor curve by a constant amount as a result of changing the velocity profile once the elastic sublayer is formed, and hence the deviation between the original curve and the shifted one will increase with Reynolds number.

Conclusions

From the results of the experiments conducted on Iraqi and Saudi crude oils, one can conclude the following:

1. An appreciable and measurable D.R. has been achieved by adding only 3 ppm of solvent concentration to crude oil.
2. Drag reduction increases with increasing pipe diameter, and this gives a significant indication for industrial application, since the pipe sizes used in this study are close to the ones used in transporting Iraqi and Saudi crude oils.
3. Drag reduction increases with increasing Reynolds number (fluid flow rate). These results show a positive indication, since most of the fluid flows in industrial applications lie in the turbulent region. However, this conclusion is restricted for crude-oil-related applications due to the recommended pumping velocity in oil industry, which should not exceed 2 m/s.
4. Drag reduction increases with increasing solvent concentration up to a certain limit. The optimum concentration found from experiments is 9 ppm for Iraqi crude oil and 10 ppm for Saudi crude oil.

Recommendations

The following recommendations for further studies can be made:

1. The effects of pipe roughness and pipe length on D.R. need to be investigated.
2. Pipes of larger diameters need to be included in further studies.
3. The effect of pipe fittings such as elbows and valves on D.R. needs to be studied.
4. The effects of fluid physical properties such as density and viscosity on D.R. need to be investigated.
5. A pressure transducer should be used for measuring the pressure drop due to its high accuracy, especially in highly turbulent flow.

Acknowledgments

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Appendix A: Physical and chemical properties of GEM solvent

Boiling point	98°C
Ignition point	inflammable
Freezing point	−4°C
Poisonous effect	nil
Specific gravity	1.08
Color	colorless
Phosphate content	nil
pH	11.6