# FACTORS AFFECTING DRAG REDUCTION BY NON IONIC SURFACTANT ADDITIVES

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## العوامل التى تؤثر فى تقليل الفواقد الهيدروليكية عند إستخدام إضافات من المركبات ذات النشاط السطحى غير الأيونية

ملخص البحث :

يتناول هذا البحث دراسة عملية لتقليل الفواقد الهيدروليكية عند سريان الماء فى خطوط الأنابيب بإستخدام أنواع معينة من الكحوليات البولى أوكسى إيثيلينية (مركبات غير أيونية ذات نشاط سطحى) مذابة فى الماء. وتمتاز هذه المركبات - كما أثبت البحث - بخاصية إستعادة نشاطها فى تقليل تلك الفواقد بعد تدهورها ميكانيا عندما تزول قوى القص الميكانيكية التى تسبب تدهورها . وقد تمت الدراسة المعملية لدراسة تأثير درجة الحرارة ودرجة التركيز لهذه الإضافات وقطر الأنبوبة والقص الميكانيكى وكذا تأثير إضافة مواد إلكتروليتية لتلك المواد على تقليل الفواقد الهيدروليكية عند أو بالقرب من درجة حرارة التعكير. وتم إجراء التجارب فى أنابيب ذات أقطار ٦٫١٧ مم و ٢٫٦٩ مم وكذلك ٠٫٨١ مم عند أرقام رينولدز تتراوح بين ١٠٠٠ و ٢٠٠٠٠٠. وأثبتت النتائج الفعالية الكبيرة لتلك المركبات فى تقليل الفواقد الهيدروليكية والتى تصل إلى نهايتها العظمى عند أو بالقرب من درجة حرارة التعكير وتزيد الفعالية كلما قل قطر الأنبوبة.

ABSTRACT

Drag reduction by using certain polyoxyethylene alcohol non-ionic surfactants dissolved in water has been investigated experimentally. For these compounds it is proved that the mechanical degradation is reversible and the drag reduction is regained when shear stress is decreased. For solvent Reynolds number ranges from $10^3$ to $2\times10^5$ in tubes of 6.17, 2.69 and 0.81 mm, the effects of concentration, electrolytes addition and mechanical shear on the drag reduction at/or near the cloud point temperature, have been investigated experimentally. The drag reduction was found to be maximum at/or near the cloud point.

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## 1- INTRODUCTION

The phenomenon of drag reduction has been known for about 40 years, [1] , and has been exploited spectacularly in recent years by high polymer additions to the crude oil in the Alaska Pipeline in Alaska, [2 & 3]. Very low concentrations of high polymer have permitted to increase the flow rate by about 10 to 20 % without increasing the pumping pressure. While high polymer drag reduction has been studied extensively, the use of non-ionic surfactants, which form large micelles in aqueous solution, has received much less attention. Zakin and Chang, [4], observed significant amount of drag reduction in the turbulent flow of some aqueous non-ionic surfactant solutions at temperature near their cloud point temperature. They suggested that large agglomerates were formed with molecular weights comparable to those of high polymer drag reducers. The resultant solutions had high relative viscosities and gave pronounced drag reducing behavior. Similar results were obtained by adding electrolytes, particularly those containing polyvalent anions like sulfate, thiosulfate or phosphate, at fixed temperature until the cloud point was approached.

This behaviour resembles that of aqueous soaps such as sodium oleate as reported by Savins, [4 & 5]. Both of these types of additives as well as complexes formed by solutions of Cetyl Trimethyl Ammonium Bromide mixed with $\alpha$ or $\beta$-Naphthol, [7], are "repairable". That is, although they degrade mechanically under high-shearing stresses, and show little or no drag reduction behaviour under these conditions, they recover their drag reducing ability when the stress level is lowered. The complexes are not practical because they are chemically unstable. The aqueous soaps are sensitive to the presence of Cations such as calcium, which are present in most water systems of interest, and cause precipitation out of the calcium soap. The non-ionic surfactants, however, are both chemically stable and insensitive to the presence of cations and hence are potentially more useful.

This work is concerned with the investigation of a number of additional non-ionic surfactants. Some of which are more effective than any previously studied, [4, 8, 9 & 10]. The effects of temperature, composition of surfactants, electrolyte addition, surfactant concentration, tube diameter and mechanical shear are shown.

## 2- EXPERIMENTAL INVESTIGATION

The object of this work is to find the promising non-ionic surfactant drag reducing agents, suitable for different working temperatures. The effects of surfactant structure, concentration, electrolyte addition, tube diameter and the mechanical shear, on their drag reduction were investigated experimentally. A set up was built, [11], to measure the friction loss coefficient, and consequently the drag, in pipes of different diameters. The experimental work has been carried out as follows :

1- preparation of different types of non-ionic surfactant

additives with different concentrations,
2- measuring the relative viscosities for aqueous solutions of different concentrations of additives,
3- measuring of the cloud ppoints for solution of both surfactants and surfactants mixed with salts,
4- measuring of the loss coefficient for different diameters of pipes of length = 0.576 m,
5- checking the fluid properties as a function of circulation time to find the sensitivity of additives to mechanical degradation.

The pressure friction loss coefficient has been measured for different fluids at different concentrations, temperatures, pipe diameters and flow conditions. The pressure drop was measured by pressure transducers of a range 0 t0 8 bar, while the flow rates were measured by a magnetic flow-meter. The working temperature was kept almost constant within $\pm$ 0.1° C, during the whole experiment by means of a digital thermostat.

For flow in pipelines, the mean velocity $u$, the pressure drop $\Delta p$, the Reynolds $Re$ and the drag reduction $D_r$ may be given by the following relations, [11] :

$$u = Q / ( \rho D^2/4 ) \quad (1)$$

$$\Delta p = \lambda L/D ( \rho v^2 / 2 ) \quad (2)$$

$$Re = \rho D v / \mu \quad (3)$$

$$D_r = ( 1 - \lambda / \lambda_v ) \quad (4)$$

## 3- RESULTS AND DISCUSSION

The effects of the temperature, surfactant concentrations, salts and other additives as well as the mechanical shear on the drag reduction on non ionic surfactant solutions were studied. The tube diameters were chosen as 0.81, 2.69 and 6.17 mm.

### 3.1 - Effect of Temperature

The variation of the friction factor with different Reynolds numbers for a 1 %. (by weight), *Brij 96* and *Alfonic 1214* solutions are shown In Fig.(1) to (3). The solid lines are for the conventional friction factor for Newtonian fluids. The cloud point of *Brij 96* is 56.5° C, and for *Alfonic 1214* is 52.1 °C. The results show that the drag reductions attain their maximum value near the cloud point.

### 3.2- Effect of Electrolyte Additions

Figure (4) shows the friction factor vs. the solvent Reynolds number with/ and without salt, (as an electrolyte), for *Brij 96* in a 2.69 mm tube. The results are shown at cloud points. The effect of electrolyte addition at constant temperature is found to be similar to that of increasing the temperature. They act by dehydrating the ether linkage.

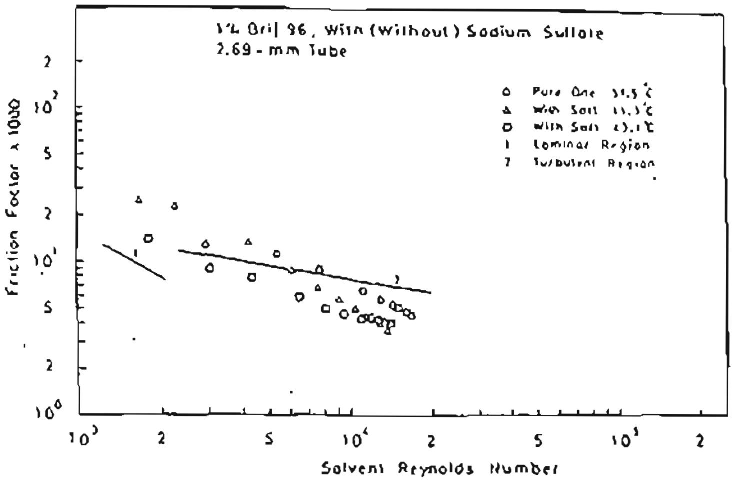


Fig.(4) Friction Factor For 1 % Brij 96 with/without 0.5 N $Na_2SO_4$ and 2.69 Tube.

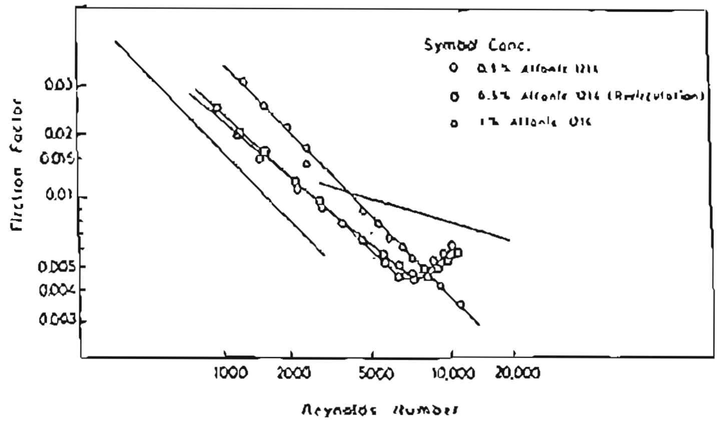


Fig.(5), Effect of Concentration on Drag Reduction.

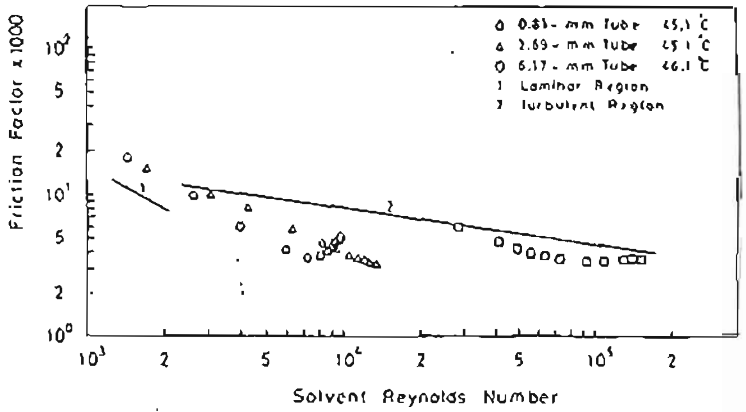


Fig.(6), Friction Factor for 0.25 % Brij 96 and 0.5 N $Na_2SO_4$

The obtained results show that the effect of concentration increase is similar to that of adding electrolyte at fixed temperature below the cloud point. In each case the agglomerates are stabilized and become more resistant to mechanical degradation.

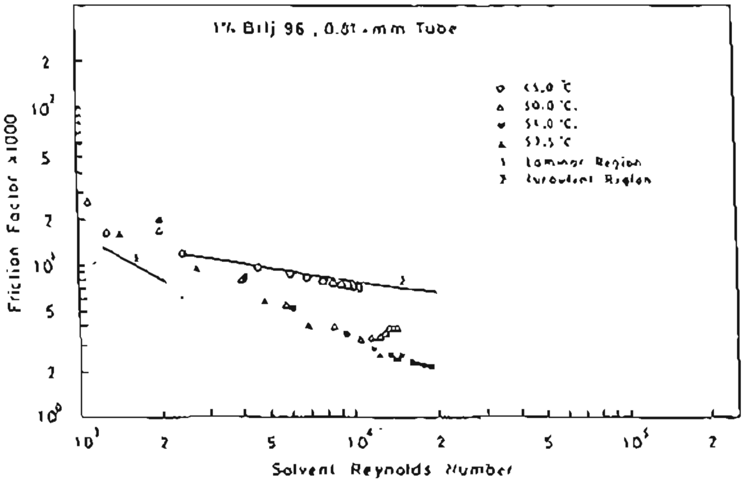


Fig. (1) Friction Factor For 1 % Brij 96 and 0.81 mm Tube

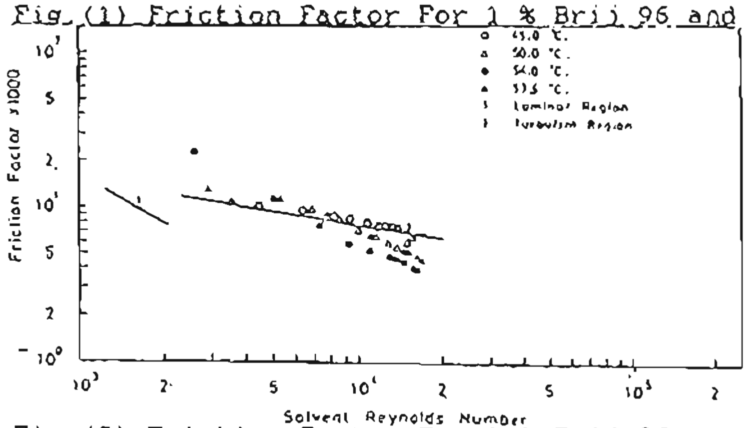


Fig.(2) Friction Factor For 1 % Brij 96 and 2.69 mm Tube

### 3.3- Effect of Surfactant Concentration

The effect of surfactant concentration on drag reduction is shown in Fig.(5). At low Reynolds numbers, the 1 % *Alfonic 1214* solution with 0.3 *N* $Na_2SO_4$ at 30° C, which is close to the cloud point, has a high relative viscosity, ($\eta_R$=2.3). The laminar data lie above that of 0.5 % solution. For 0.25 % *Brij 96* with 0.5 *N* $Na_2SO_4$ at the cloud point in three different tubes are shown in Fig.(6).

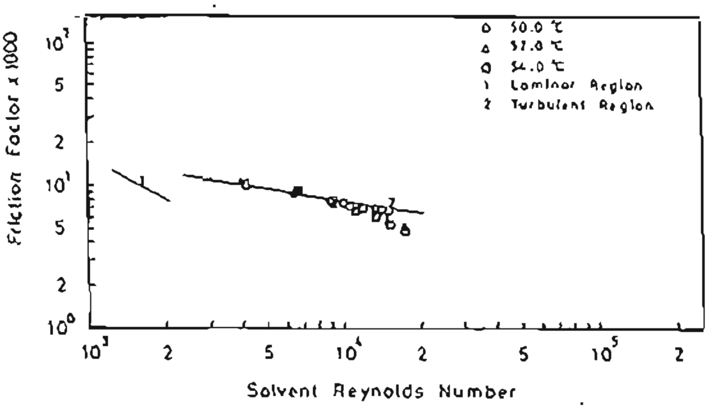


Fig. (3): Friction Factor For 1% Alfonic 1214 and 0.81 mm Tube

### 3.4- Effect of Tube Diameter

Figure (7) shows the effect of tube diameter on drag reduction for 0.5 % *Brij 96* with 0.5 *N* $Na_2SO_4$ at 45° C. The results show that the drag reduction increases as the tube diameter decreases. This may be attributed to the relatively large boundary layer thickness as compared to the pipe diameter. The drag reduction occurs mainly due to the surfactant effects on the boundary layer.

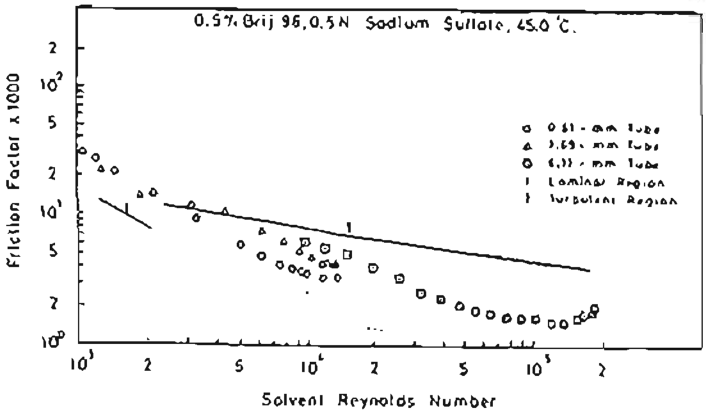


Fig.(7), Effect of Tube Diameter on Drag Reduction.

### 3.5- Effect of Mechanical Shear

Drag reducing solutions of soaps and surfactants loose their drag reducing ability above some critical wall shear stress. at which mechanical degradation begins.

In Fig.(5), a solution of 0.5 % *Alfonic 1214* + 0.3 *N* $Na_2SO_4$ at 30°C was pumped at maximum flow rate for 12 hours. Then it was returned at decreasing Reynolds numbers. The drag reduction results after mechanical shear above the critical shear stress for degradation are very close to those of fresh unrecycled solutions. This shows that the mechanical degradation is reversible process.

## 4- CONCLUSIONS

Some non-ionic surfactants formed from a straight chain alcohols and ethylene oxide moieties of proper sizes are effective drag reducers at/or near their cloud points.

The effect of concentration increase is found to be similar to that of adding electrolyte at a fixed temperature below the cloud point, or increasing the temperature to approach the cloud point. In each case the agglomerates are stabilized and became more resistant to mechanical degradation.

The effect of tube diameter on the drag reduction seems to be similar to that shown by high polymers: the drag reduction increases as the tube diameter decreases.

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