Effect of Drag Reducing Agents - Polymers and Surfactants Alone and in Combination on Efflux Time in Gravity-Driven Flow Systems

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ABSTRACT: *Determination of efflux time for draining water, a Newtonian liquid from a large cylindrical open tank through a hole located at the center of the bottom of the tank has been used to study the effect of the addition of water-soluble drag-reducing agents. Two polymers (Polyacryl amide, (PAM) and guar gum), two surfactants (Lauryl sulfate and surf excel), and mixed solutions of guar gum and surf excel were studied. Four different concentrations of drag-reducing agents were considered for their impact on efflux time. There is a maximum of 1.3% reduction in efflux time (i.e drag reduction) with the addition of aqueous solutions of poly acryl amide while there is 2.8% maximum drag reduction due to guar gum. In the presence of aqueous solutions of Lauryl sulfate surfactant, there is an increase in efflux time i.e (enhancement of drag) while there is a maximum of 2.3% drag reduction when aqueous solutions of Surf excel are used. With the mixed solutions of Surf excel and Guar gum, a maximum drag reduction of 2.9% has been observed. This suggests that drag reduction is possible in the tank. and also, at the contraction point at the bottom of the tank. In the concentration ranges considered, polymers either had no effect or reduced drag while the same conclusion cannot be drawn in the case of surfactant solutions.*

KEYWORDS: *Efflux time; Drag; Polymers; Surfactants; Once through the system.*

INTRODUCTION

The time required to drain process vessels solely, under the action of gravity is called efflux time and is of considerable practical interest in a variety of industries like chemical, food, and pharmaceutical [1]. Solutions to these draining problems have appeared for several cases of storage tanks / vessels with different geometrical configurations or shapes that are mostly used in industrial practices [2].

One of the methods of draining liquids from the storage vessels can be through a restricted orifice [3], or an exit piping system consisting of one or more pipes [4].

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The pipe flow is normally laminar when the Reynolds number is < 2100 and turbulent for Reynolds numbers > 4000.

When a liquid from a large open storage tank is drained by an exit piping system, the flow in the tank ought to be laminar while the flow in the exit pipe can be laminar or turbulent depending on the diameter of the exit pipe and physical properties of the liquid to be drained. Even though the majority of the industrial flow problems are turbulent, the laminar flow has its share of importance as in the flow of a liquid from a large tank through an exit piping system [5] or flow in a U-tube manometer [6].

Capillary viscometers make use of Poiseuille's law (which is derived based on laminar flow conditions) to measure the relative viscosity of liquids [7]. Laminar flow describes the flowing of blood through blood vessels. A survey of septic tank design showed that short-circuiting is minimized and effluent quality is improved when quiet, laminar, fluid flow occurs[8]. Laminar flow ventilation is also used in modern orthopedic operating theatres to reduce the number of infective organisms present in the air, which may lead to post-operative wound infection [9].

The very significant high potential for aerodynamic drag reduction is seen in laminar flow control by boundary layer suction [10]. The flow of a real liquid flow through pipes is hindered by drag which manifests itself into friction. The reduction in friction or drag is achieved by various means. The use of linear chain polymers of high molecular weight and surfactants for reducing this friction is considered to be one of the active means of drag reduction [11].

Earlier studies report a reduction in drag in a U-tube manometer (where the flow is laminar) using polyethylene oxide polymer solutions [6]. The reduction in drag in the above is attributed to minimizing disturbed flow conditions. It is also reported in the literature that drag reduction with polymers is possible in laminar flow conditions if the flow is non-uniform [11]. There are claims that drag reduction in laminar flow could not be achieved by polymer solutions [12], it has been stated that drag reduction in laminar flow is less effective than in turbulent flow([13].

The objective of the present work is to verify how effective drag reduction in laminar flow can be for a once-through system when aqueous solutions of polymers and surfactants are used. Polymers and surfactants are considered active means of drag reduction. Polymers reduce drag within their concentration ranges of 1 to 10 ppm, while for the same reduction in drag, the concentration of surfactants required is extremely high (500 ppm to 2500 ppm).

Fig. 1: Cylindrical tank with level indicator.

EXPERIMENTAL SECTION

The equipment used for conducting the experiments consisted of a cylindrical tank (shown in Fig. 1) of 0.38 m diameter with a hole of 4mm diameter provided at the bottom center of the tank. The hole is closed by a plug while filling the tank with the test solution. The tank is filled with water or aqueous solutions of drag-reducing agents as the case may be and allowed to stabilize. When the flow is stabilized, the plug is removed, and the stopwatch is simultaneous. The stopwatch can be read within one second. The time taken for draining the liquid from an initial height of 0.44 m to a fixed final height of 0.02m is noted. From these data, the fluid velocity in the tank is obtained from which the Reynolds number has been estimated and found to be 97 which is well within the laminar region**.** This procedure is repeated for the measurement of the efflux time of the aqueous solution of polymers and surfactants as well.

Methods of injection of polymers and surfactants

Three methods of injection of polymer solutions are described in practice [14]. These methods are a) pre-mixed solutions b) diffusing injection method and c) polymer thread injection.

Since the flow in the present case is once through (i.e liquid from the tank flows only once through the drain hole), the preferred method of injection is pre-mix. The method of preparation of the drag-reducing solutions is presented in Table 1. The experiments are conducted for a fixed initial height of liquid in the tank.

Table 1: Method of preparation of drag-reducing solutions.

Drage reducing agent	Concentrations (ppm)	Method of preparation of DRA
Polyacrylamide (PAM) and guar gum	10,5, 2.5 and 1	The stock solution is prepared by dissolving the polymer in water with agitation for 24 hours to ensure the homogenous solution is formed and this stock solution is suitably diluted to the desired concentration.
Sodium Lauryl Sulfate and surf excel detergent	2000,1500, 1000 and 500	The stock solutions are prepared by dissolving the known mass of surfactant n water and then diluting the stock solutions by adding water to arrive at the desired concentration.
Mixed solutions of surf excel and Guar Gum	10,5,2.5 and 1 ppm	The stock solution is prepared by mixing known masses of Guar Gum and Surf excel with agitation for 24 hours to ensure the homogenous solution is formed and this solution is diluted to the desired concentration the weight ratios of Surf excel and Guar Gum considered are 0.5 g : 0.5 g (1:1 ratio), 0.75g :0.25 g (3:1 ratio), 0.6 g :0.4 g (1.5 :1 ratio)

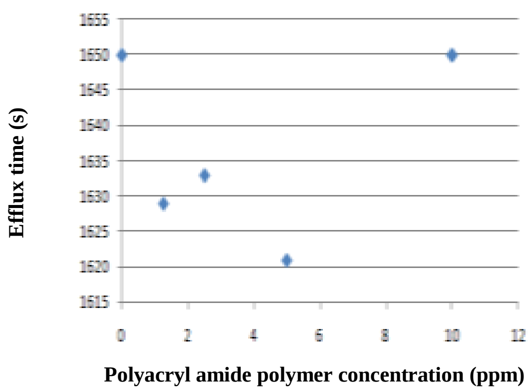

Fig. 2: Variation of efflux time concerning polyacrylamide polymer concentration.

The tank is cleaned and allowed to dry between tests. The tests are repeated to verify the consistency of data.

RESULTS AND DISCUSSION

When the liquid is drained from the tank, the draining is slow and the draining can be approximated to a Pseudo steady state. The assumption could be valid if the ratio of the cross-sectional area of the tank to the cross-sectional area of the exit hole is >100 [3]. In the present case, this ratio is larger than >100 and thereby justifying the assumption of pseudo steady state. Experiments with water showed the efflux time was 1650 s.

Variation of efflux time with the concentration of polymers

The effect of Polyacrylamide polymer as a drag reduction agent on efflux time is shown in Fig. 2. The variation in the efflux time when the Polyacryl amide concentration is increased by fivefold is shown in the plot of data given Fig. 2. In the figure, 0 ppm represents the efflux time for water.

The plots of the data showed that at 10 ppm concentration of polymer, the efflux time 1650 secs was found to be the same as that of water free of Polymer (as reported earlier) For other concentrations of polymer solutions less than 10 ppm, the efflux time was found to be less than that of water. This suggests that flexible polymers like poly acryl amide remain neutral (No reduction in efflux time) without any drag reduction (reduction in efflux time) at low Reynolds numbers. The variation in the efflux time for the range of PAM concentrations used was just nominal about < 2%. A similar observation was reported by *Yacine Amarouchene et al.* [15]. It can be seen from the plot that the lowest efflux time (maximum drag reduction) was obtained for 5 ppm concentration of the polymer.

The variation of efflux time against concentration for Guar Gum polymer solutions is shown below in Fig. 3.

Fig. 3 shows that efflux time is less compared to that for water (1650 secs) for all the concentrations of Guar Gum polymer covered in the present study.

It is just interesting to see the efflux time was minimum at 5 ppm, for both cases of Polyacrylamide and Guar Gum. Both the polymers may not be that effective in reducing the efflux time or drag reduction at low Reynolds numbers – laminar region.

Variation of efflux time with varying concentrations of surfactants

The data on efflux time with Lauryl sulfate surfactant as the drag-reducing agent is shown in Fig. 4 while the data

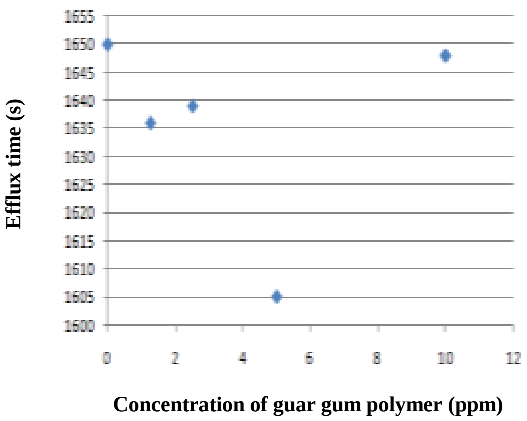

Fig. 3: Variation of efflux time with the concentration of Guar Gum.

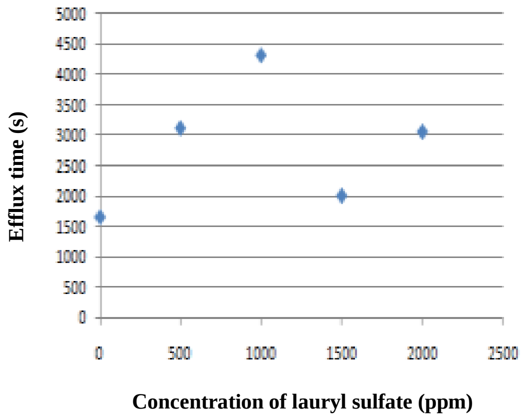

Fig. 4: Variation of efflux time with concentrations of both Lauryl sulfate.

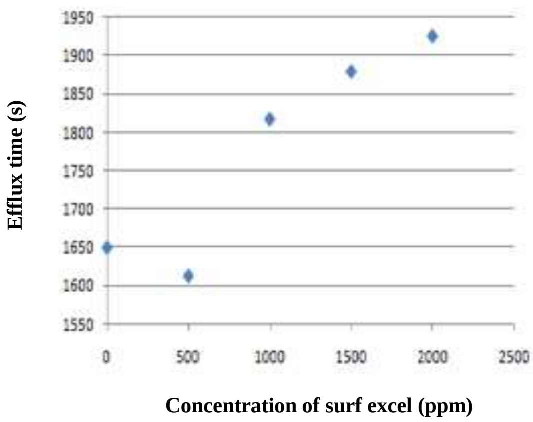

Fig. 5: Variation of efflux time concerning concentration for Surf excel detergent.

on efflux time for Surf Excel as the drag is shown in Fig. 5.

The efflux time for all concentrations of Lauryl Sulphate was found to be higher than water (1650 sec) indicating a decrease in Drag Reduction. However, efflux times were found to increase with increased concentration of this detergent up to 1000 ppm, while beyond 1000 ppm a drastic fall in efflux time was observed at 1500 ppm indicating an increase in Drag reduction. Further increases in concentration beyond 1500 ppm showed a gradual increase in efflux time. In the case of Surf excel, a minimum efflux time at 500 ppm, which is less than that of water (1650 s), and for other concentrations of Surf Excel the efflux times were found to be increasing. It can be concluded that as the concentration of drag-reducing surfactant increases, at a certain critical concentration, drag reduction was found to reverse. [16].

The surface tension for Surf Excel is reported as 28 dyne/cm while Lauryl Sulfate is reported as 31.5 dyne/cm [17]. The reduction in surface tension of Surf Excel compared to that of Sodium Lauryl Sulphate can be attributed to the reason for the better drag reduction performance of Surf Excel at 500 ppm concentration over Lauryl Sulphate.

The data in Fig. 4 and Fig. 5 however, suggest that it is not possible to generalize whether surfactants effectively reduce drag when the flow is Laminar.

Figs. 2,3,4 and 5 reveal that Guar Gum reduced drag better than poly acryl amide and surf excel reduced drag relatively better than lauryl sulfate. Hence experiments are conducted using mixed solutions of Guar gum and Surf excel detergent.

Variation of efflux time concerning the concentration of mixed solutions of Guar Gum and Surf excel

In view of the failure of the inefficient drag reduction ability of polymers alone and surfactants alone, it is now planned to study the combination of these agents in certain proportions or ratios which might offer good results in reducing drag even under laminar flow conditions. It has now been attempted to use the combination of Surf Excel and Guar Gum in 1:1 ratio (0.5 g of Surf Excel detergent and 0.5 g of Guar Gum bio-polymer) and the efflux time data is shown in Fig. 6.

The plot in Fig. 6 revealed that at all concentrations of mixed solutions, drag reduction is conspicuous compared

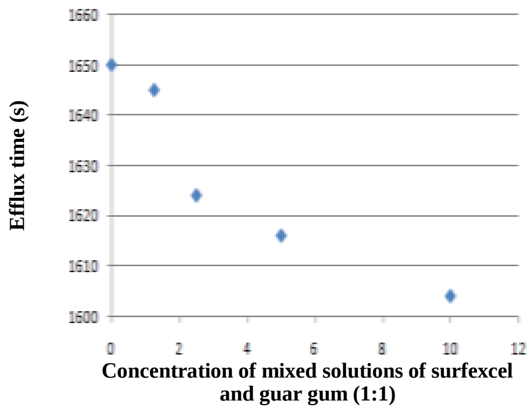

***Fig. 6:** Variation of efflux time concerning concentration for mixed solutions of surf excel and guar gum (0.5 g of Surf excel : 0.5 g of Guar Gum, 1:1 ratio).*

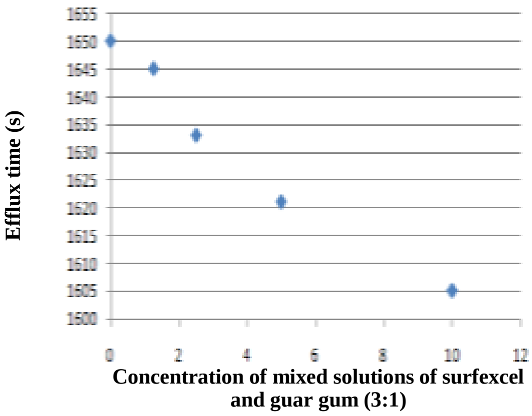

***Fig. 7:** Variation of efflux time with concentration for mixed solutions of Surf excel and Guar Gum (weight ratio of surf excel to Guar Gum = 3:1).*

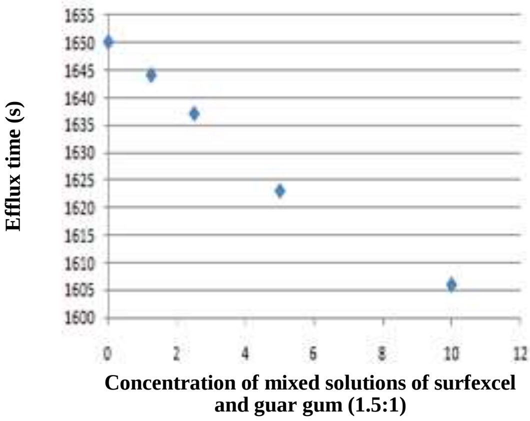

***Fig. 8:** Variation of efflux time with concentration for mixed solutions of Surf excel and Guar Gum (weight ratio of Surf excel to Guar Gum = 1.5:1).*

to that of only pure water (1650 s), pure Surf Excel, and Pure Guar Gum alone. A gradual increase in drag reduction with an increase in the concentration of the mixed solution, approaching its minimum at 10 ppm (Efflux time <1650 sec). This is further confirmed in the following figures show different combinations of Surf Excel and Guar Gum (3:1 and 1.5:1) in Fig. 7 and Fig. 8 respectively. A gradual fall in the efflux time and an increase in the drag Reduction could be observed from the data of these plots.

It can be concluded from Figs. 6, 7, and 8 that mixed solutions of Surf excel and Guar Gum were found to reduce drag **for** all the concentrations of the mixed solutions considered in the study. The minimum (lowest) efflux time was observed at 10 ppm for all the weight ratios considered. The efflux time for all these **cases** is less than that of either aqueous solutions of Polyacryl Amide polymer or aqueous solutions of Guar gum. Moreover, in contrast to polymer solutions, Drag Reduction is quite a significant relative for all the concentrations of mixed solutions used in this investigation.

% Drag reduction

% drag reduction is calculated from the following relation.

$$\%DR = 100 \times \left(\frac{t_{WAT} - t_{DRA}}{t_{DRA}} \right)$$

Minimum efflux time is the indication of Maximum Drag reduction. The maximum drag reduction for Polyacryl Amide, Guar gum, Surf excel, and also for mixed solutions of Guar gum and Surf excel is shown in the table below (Table-2). The data on Lauryl sulfate is not shown in the table because at all the concentrations of lauryl sulfate considered in the present study, there is drag enhancement (increase in efflux time) compared to water.

CONCLUSIONS

The following are the conclusions of the study:

- The maximum drag reduction that is obtained with Poly Acryl Amide polymer is 1.3% and also with Guar gum is 2.8%. This suggests that polymers are less effective in laminar flow. The data also suggests that polymers remain neutral or drag-reducing.
- Surfactants solutions considered are either drag-reducing or enhance drag. Hence it is not possible to generalize the drag reduction behavior in laminar flow.

Table 2: Maximum drag reduction by polymers, surfactants and their combination.

Polymer	Concentration at which minimum efflux time is obtained, ppm	Maximum % DR
Poly acryl amide	5	1.3
Guar gum	5	2.8
Surf excel	500	2.3
Mixed solutions of surf excel and guar gum (1:1)	10	2.9
Mixed solutions of surf excel and guar gum (3:1)	10	2.7
Mixed solutions of surf excel and guar gum (1.5:1)	10	2.7

Surf excel detergent is a better drag-reducing agent compared to lauryl sulfate

- Mixed solutions of Guar gum and Surf excel were found to be better drag-reducing mixes even at low concentrations under Laminar flow conditions. The possible reasons for drag reduction in this case are:

a) minimization of flow disturbance at the contraction point between the tank and the aperture located at the center of the bottom of the tank [5]

b) Surfactant molecules form micelles around the polymer chains and the two additives form a kind of reinforced concrete structures, which were more complex and more effective in restraining vortices, leading to the intensification of drag reduction in the enhanced zone and stable zone compared to pure surfactant solution [18]

Nomenclature

t_{WAT}	Efflux time with water
t_{DRA}	Efflux time with a drag-reducing agent
%DR	% Drag reduction

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