Drag Reduction by Surfactant Solutions in Gravity Driven Flow Systems

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ABSTRACT: *Efflux time measurements are carried out for gravity draining of a liquid from a large cylindrical tank (where the flow is essentially laminar) through single exit pipe in the absence and presence of Cetyl Pyridinium Chloride (CPC) surfactant solutions. The variables considered are initial height of liquid in the tank, dia. of tank, length of the exit pipe and concentration of surfactant. The dia. of exit pipe in all the cases however remained constant. Drag reduction is expressed as the difference in efflux time in the absence and presence of surfactant solutions. Maximum drag reduction at optimum surfactnat concentration is reported. It is observed that during draining, Froude number remains constant.*

KEY WORDS: *Efflux time, Cylindrical tank, Surfactant, Exit pipe, Froude number.*

INTRODUCTION

Chemical industry uses different shapes of storage vessels. The reasons for the choice of the typical shape or geometry may be attributed to convenience, insulation requirements, floor space, material costs, corrosion, safety considerations etc. The time required to empty the liquid content from the storage vessel is known as efflux time [1] and is very important not only from productivity point of view, but also under emergency situations.

Mathematical equations for efflux time for gravity draining of a Newtonian liquid from a cylindrical tank through an exit pipe is (for turbulent flow in the exit pipe) is reported [2] The authors assumed constant friction factor while developing the mathematical equation.

The assumption of constant friction factor is supported by *Subbarao* and co-researchers [3] while develpoing the efflux time equation for turbulent flow in the exit pipe. The authors reported the following equation for efflux time

$$t_{eff} = \sqrt{\frac{2}{g_m}}\left(\sqrt{H+L} - \sqrt{H'+L}\right), \qquad (1)$$

Where , t_{eff} is the efflux time and g_m is modified form of acceleration due to gravity and is given by

$$\frac{g_m}{g} = \frac{1}{\left(1+4f\frac{L}{d}\right)\left(\frac{A_t}{A_p}\right)^2} \qquad (2)$$

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Where f is the friction factor, L is length of the exit pipe, d, diameter of exit pipe, A_t and A_p are cross sectional areas of tank and exit pipe respectively. The authors also mentioned that:

$$\frac{g_m}{g} \propto (Fr)^2 \quad (3)$$

Where Fr is the Froude number.

During draining from vessel, the liquid encounters some friction and this friction is a measure of drag. This drag increases drastically when fluid flow transforms from laminar in the tank to turbulent flow in the exit pipe. Hence drag reduction options are to be explored. This can be achieved either by hydrophobic surfaces [4], air injection [5], polymer solutions [6] or surfactants [7].

Work is reported for reducing drag using different concnetrations of polyacrylamide polymer solutions with single exit pipe system [3]. The authors arrived at 10ppm optimum concentration of polymer solutions. The authors also stated that polymer additions decrease the efflux time and hence increase the Froude number.

Subbaro and other researchers performed drag reduction experiments for two exit pipe system under turbulent flow conditions in each of the exit pipes [8]. The extent of increase in Froude number is observed to be more for two exit pipe systems compared to single exit pipe system in the presence of polymer solutions.

Reddy & Subbarao [9] stated that Froude number can also be increased by changing the geometry of the vessel. They theoretically compared the efflux time for cylinder with that of spherical tank and showed that Froude number for a liquid drained through spherical tank is more than that of a cylinder.

Subbarao [10] compared the efflux time between cylinder and cone and showed that the Froude number is more for cone than cylinder.

Gopal Singh and other researchers [11] used polyacryl amide and polythene oxide as polymers in their studies on efflux time and reported optimum concentrations for both laminar flow and turbulent flow in the exit pipe. They also stated that Froude number is influenced by type of polymer used and flow.

All the studies mentioned above changed the geometry or used different polymer additions for increasing the Froude number, since polymer solutions work better in once through systems and at lower concentrations. Froude number can also be influenced by surfactant additions. To the best of authors knowledge, no experimental evidence of drag reduction using surfactant solutions in gravity driven flow is reported.

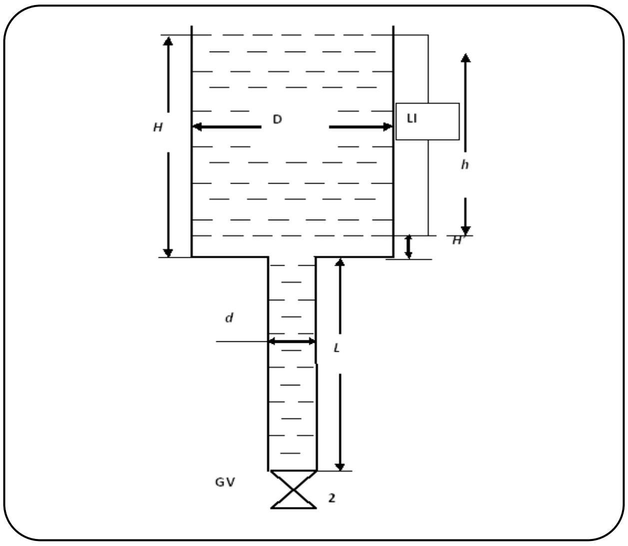

Fig. 1: Tank along with exit pipe.

The scope of the present study is to assess whether drag reduction is significant enough to warrant the use of surfactant solutions. The surfactant chosen is Cetyl Pyridinium Chloride (CPC). The % reduction in efflux time in the absence and presence of surfactant solutions is reported as % reduction in drag.

EXPERIMENTAL SECTION

Description of apparatus:

The schematic diagram of the apparatus and the equipment are shown in Fig 1. The equipment used for experimentation consisted of known diameter tank rigidly placed on a steel structure. A mild steel pipe of known diameter (d) is welded to the tank at the centre of the bottom of the tank, served as an exit pipe. A Gate Valve (GV) provided at the bottom most point of the exit pipe, served as control valve for draining of liquid from the tank. A transparent plastic tube (LI) provided to the tank served as level indicator during draining operation.

Tanks of three different diameters of 0.37, 0.34 and 0.30m and four exit pipes of of 0.25, 0.5, 0.75 and 1m lengths are used for performing the experiments. The diameter of exit pipe remaied constant at 0.004m. Efflux times

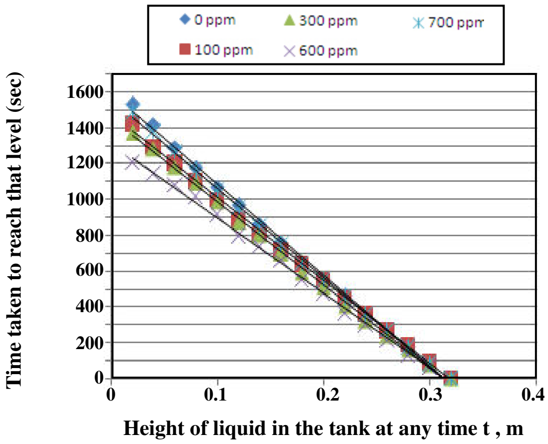

Fig. 2: Draining pattern for different concentrations of surfactant solutions (Dia of tank=0.3m and exit pipe length =0.25m).

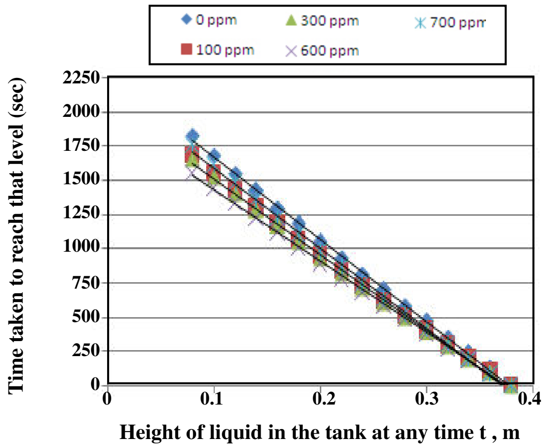

Fig. 3: Draining pattern for different concentrations of surfactant solutions (Dia of tank=0.34m and exit pipe length =0.25m)

measurements are carried out using a stopwatch with 1 sec accuracy.

Experimental procedure

Part A

Gate Valve (GV) is closed and the tank was filled up to the mark and allowed to stabilize. The stopwatch was started immediately after the opening of the bottom valves. The drop in water level was read from the level indicator. The time was recorded for a fall in the liquid level to a predetermined level of 0.02 m just above the tank bottom. The experimental efflux time is designated as t_{act}. The experiments are repeated and the measurements were taken to check the consistency of data.

Part B

The stock solution of Cetyl Pyridinium Chloride (CPC) is prepared by dissolving 2.0204 g of Cetyl Pyridinium Chloride (CPC) in 1L of water. The solution is stirred for 1 hour and then allowed to hydrate for 24 hours. The clear solution without any non-homogeneity is diluted suitably to prepare 100, 300, 600 and 700ppm solutions. The pre-mixed solutions are added to the cylindrical tank and efflux times are obtained in the manner described above.

RESULTS AND DISCUSSION

Tank draining pattern

The tank draining pattern (i.e time required to reach a particular height from a given initialheight) for 0.30 m dia. tank and for 0.25m exit pipe length is shown in Fig. 2.

Since the volume of liquid in the tank at any time is a linear function of height of liquid in the tank (because its cross-section is constant), the draining pattern is linear. The plot also suggests that optimum concentration of surfactant (i.e minimum draining time) is at 600ppm.

The posiible reason for drag reduction is due to the large elongational viscosity of the polymer solution; this stabilizes the turbulent boundary layer, leading to less turbulent energy generation, and hence less dissipation as reported by *Drappier* and other researchers [12].

The trend for 0.5, 0.75 and 1m is observed to be same and hence it is concluded that the optimum concentration is 600ppm and is independent of length of exit pipe.

Variation of efflux time with diameter of the storage vessel

When the diameter of the vessel is changed to 0.34m by keeping the exit pipe length at 0.25m, the plot of variation of efflux time with initial height of liquid in the tank is shown in Fig. 3.

In this case also, the optimum concentration is at 600 ppm.

The trend observed for 0.37m and 0.3m diameters of storage tank is found to be same and hence it is concluded that the optimum concentration is independent of diameter of storage tank.

Variation of Froude number with initial height of liquid in the tank

Froude number (Fr) is defined in [13]:

$$\mathrm{Fr} = \frac{V_2^2}{2g(H+L)} \quad (4)$$

Table 1: % Calculation of maximum drag reduction.

S. No		% Drag reduction for initial height of liquid in the tank, 0.32			
		Length of the exit pipe, m			
		0.25	0.5	0.75	1
1	Dia of tank=0.3m	17	21	18	18
2	Dia of tank=0.34m	15	16	16	15
3	Dia of tank=0.37m	21	25	26	26

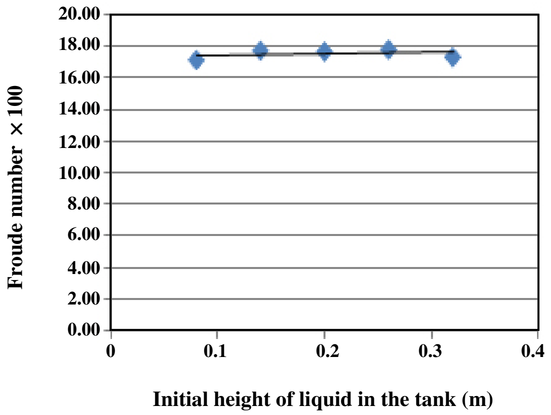

Fig. 4: Variation of Froude number with initial height of liquid in the tank (dia of tank=0.30m and length of exit pipe=0.25m).

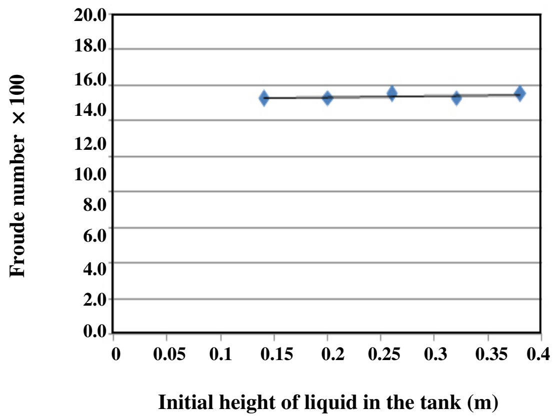

Fig. 5: Variation of Froude number with initial height of liquid in the tank (dia of tank=0.30m and length of exit pipe=0.5m).

Where V_2 is the velocity of the liquid leaving the exit pipe, g the acceleration due to gravity, H is the initial height of the liquid in the tank and L is the length of the exit pipe.

The plot Fig. 4 illustrates the variation of efflux time with initial height of the liquid in the tank for 600ppm surfactant solution.

The plot suggests that Froude number is constant and not influenced by initial height of the liquid in the tank.

The trend is similar for 0.5 m length exit pipe as well and is shown below in Fig. 5.

Even through Froude number remained constant, it is different for 0.5m length exit pipe. This suggests that Froude number is influenced by the length of the exit pipe.

3.5 Calculation of % Drag reduction :

% Drag reduction for once through systems is defined [11]

% Drag reduction = (efflux time with surfactant addition-efflux time without surfactant addition)/efflux time without surfactant addition)×100

The % maximum drag reduction at 600ppm concentration for different tank diameters and different exit pipe lengths is shown in the Table 1.

The maximum drag reduction is 26% which same as reported [3] using polyacrylamide polymer solutions at 10ppm concentration when a liquid is drained through single exit pipe system of same diameter, i.e 4X10-3m. However, The surfactant concentration required to achive maximum drag reduction is almost 60 times higher than that of polymer soutions.

CONCLUSIONS

Some of the conclusions of the above study are

1- The optimum concentration of surfactant is 600 ppm.

2- During draining Froude number remains constant and is independent of initial height of liquid in the tank.

3- The optimum concentration is not influenced by length of exit pipe as well as diameter of storage vessel the diameter of storage vessel.

4- The maximum drag reduction using surfactant solutions in gravity driven flow systems is 26% which is same as that obtained for polymer solutions. However, the optimum concentration is much higher than that of polymer solutions.

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