Drag Reduction by Anionic Surfactant Solutions in Gravity Driven Flow System

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ABSTRACT: *This paper presents efflux time experiments performed in the absence and presence of aqueous solutions of Drag Reducing Agents (DRAs) when a liquid is emptied from a large open cylindrical storage tank through an exit piping system. The drag reducing agents studied are Dodecyl benzene sulfonate anionic surfactant and a mixed solution of surfactant and sodium chloride counter ion. The variables studied are initial height of liquid in the tank, diameter of storage tank, and length of exit pipe. Drag reduction (i.e reduction in efflux time) is found be more significant in presence of mixed solutions of surfactant and its counter ion. It has also been observed that Froude umber remains constant during draining and increases upon addition of surfactant solution and also in case of mixed solutions of surfactant and its counter ion.*

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

INTRODUCTION

Different geometries of storage tanks are in use in a chemical industry. Some of the factors which can influence the selection of a particular geometry of tank are insulation requirements, floor space, corrosion requirements, material costs etc. The time required to empty the liquid content from the storage vessel is known as efflux time (*Hart & Sommerfeld,* 1995) [1] and is of utmost importance not only from productivity point of view, but also under emergency situations.

Mathematical equation for efflux time during gravity draining of a Newtonian liquid (below its bubble point) from an open cylindrical tank through an exit pipe is (for turbulent flow in the exit pipe) reported (*Donald & Barret*, 2003) [2]. The authors assumed constant friction factor while developing the equation and used a contraction coefficient values of 1.5 while comparing the experimental values with the mathematical model.

Subbarao and co-researchers (*Subbarao et al*, 2008) [3] also made the same assumption of constant friction factor and developed equation for efflux time for the same system. They stated that $\frac{g_m}{g} \propto (Fr)^2$ where Fr is Froude number, g_m is modified form of acceleration due to gravity and g is acceleration due to gravity. The simplified efflux time equation is named as modified form of Torricelli equation.

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During draining from the storage tank, the liquid encounters friction and this friction is an indication of drag. This drag increase is substantial when fluid flow transforms from laminar in the tank to turbulent in the exit pipe. Hence drag reduction options are to be explored. This can be achieved either by use of hydrophobic surfaces (*Choi et al.*, 1997 [4], *Henoch et al.,* 2006 [5]), injecting air (*L'vov et al.*, 2005) [6], using polymer solutions (*Jurban et al.*, 2006) [7] or surfactants (*Aguilar et al.*, 2006) [8].

Work is reported for reduction in efflux time (i.e. reduction in drag) using polyacrylamide polymer solutions of different concentrations for single exit pipe system (*Subbarao et al.,* 2008)[3]. The authors used $4X10^{-3}$m dia exit pipe and 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.

Subbarao and other researchers performed drag reduction using polyacrylamide polymer for the case of two exit pipe system (*Subbarao et al.*, 2010)[9]. The extent of increase in Froude number is observed to be more for two exit pipe systems than single exit pipe system with and without polymer additions.

Theoretical equations for efflux time are developed by *Reddy* and *Subbarao* (*Reddy & Subbarao*, 2011)[10], for sphere and cylinder for the case of turbulent flow in the exit pipe. For draining the same volume of the liquid, the equations so derived are compared to find out which of the tanks considered drains faster. They also noted that the ratio of efflux times is dependent only on the ratio of height of liquid in the tank to length of exit pipe. Froude number for a liquid drained through spherical tank is reported to be more than that of a cylinder.

Subbarao (*Subbarao*, 2011)[11], compared the efflux time equations between cylinder and cone for the case of turbulent flow in the exit pipe and showed that the Froude number is more for cone than cylinder.

Gopal Singh and other researchers (*Gopal Singh et al.*, 2011)[12], used polyacryl amide and polythene oxide polymers of different concentrations in their studies on efflux time and reported optimum concentrations for both laminar flow and turbulent flow in the exit pipe. They stated that Froude number is influenced by type of polymer used.

All the studies mentioned above changed the geometry of the tank or used different polymer additions for increasing the Froude number.

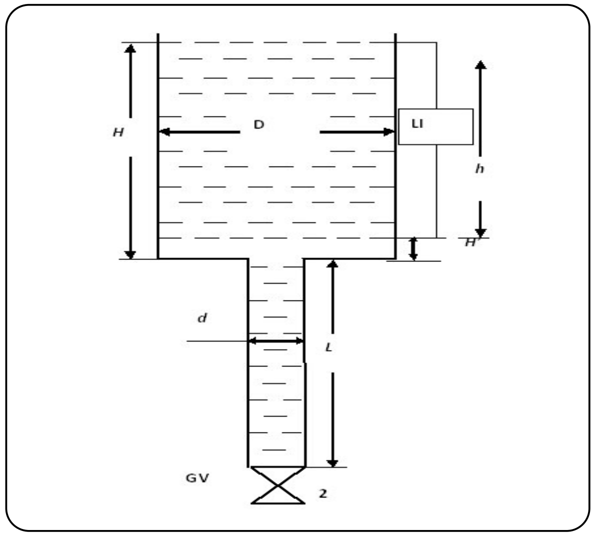

Fig. 1 : Cylindrical tank along with exit pipe.

Froude number can also be influenced by surfactant additions. To the best of author's knowledge, no work is reported for estimating the extent of drag reduction in gravity driven flow systems using anionic surfactant solutions. Anionic surfactant solutions are chosen since they are good drag reducing agents (*Wang Yi et al.*, 2011)[13]. The objective of the present study is to assess whether drag reduction is significant enough to warrant the use of surfactant solutions. The reduction in efflux time using surfactant solutions with respect to water is mentioned as % reduction in drag.

EXPERIMENTAL SECTION

Description of apparatus

The schematic diagram of the apparatus and the equipment is shown in Fig. 1. The equipment consisted of known diameter cylindrical tank rigidly placed on a steel structure. A mild steel pipe of known diameter (d) 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 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 0.37, 0.34 and 0.30m diameters, 0.25, 0.5, 0.75 and 1m exit pipe lengths and single exit pipe of diameter 0.006m are used for performing the experiments. The efflux times are measured using a stopwatch with 1 sec accuracy.

Table 1: List of experiments in the absence and presence of surfactant solutions.

S.No	Dia.of tank, m	Initial height of liquid in the tank, m	Length of exit pipe, m	Remarks
1	0.30	0.32,0.26,0.20,0.14,0.08	0.25,0.5,0.75,1	Exit pipe dia =6X10^{-3}m
2	0.34	0.38,0.32,0.26,0.20,0.14	0.25,0.5,0.75,1	
3	0.37	0.46,0.40,0.32,0.26,0.20	0.25,0.5,0.75,1	

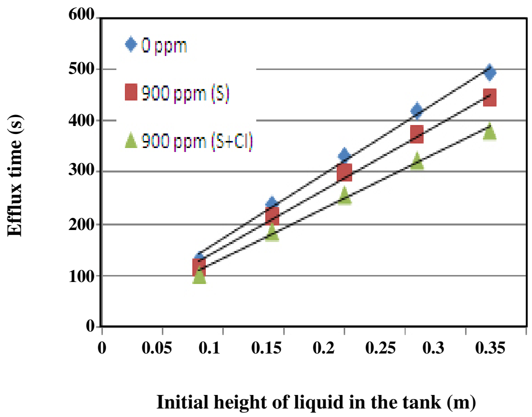

Fig. 2: Variation of efflux time with initial height of liquid in the tank (dia. of tank =0.3m, exit pipe length =0.25m).

Experimental Procedure

Part A

Gate valve (GV) was closed and the tank and exit pipe were filled with water and allowed to be stabilized. The stopwatch was started immediately after the opening of the bottom gate valve. 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 water above the tank bottom. The experiments are repeated and the measurements are taken to check the consistency of data. The lists of experiments performed are shown in the following table (Table-1).

Part B

The stock solution of Dodecyl Benzene Sulfonate Anionic(DBSA) surfactant is prepared by dissolving 2.0204X10^{-3}kg of Dodecyl Benzene sulfonate in 1X10^{-3}m^3 of water. The solution is stirred for 1 hour and then allowed to hydrate for 24 hours. Since surfactant solutions reduce drag at higher concentrations, the clear solution without any non-homogeneity is diluted suitably to prepare 900 ppm solutions. The pre-mixed solutions are added to the cylindrical tank and efflux times are obtained in the manner described above in part A.

While preparing mixed solutions consisting of DBSA and its counter ion, a mixture of DBSA and sodium chloride counter ion are taken at 1:1 weight ratio and the procedure mentioned above is used for preparing mixed solution and efflux time data is generated as mentioned in part A. The generated efflux time data is designated as t_{eff}.

RESULTS AND DISCUSSION

Variation of efflux time with initial height of liquid in the tank

The following plot (Fig. 2) shows the variation of efflux time in the absence and presence of drag reducing agents.

In the figure, experiments with water are designated as 0 ppm, with that of surfactant as (S) and mixed solution of surfactant and counter ion as (S+CI).

The plot suggests linear variation of efflux time with initial height of liquid in the tank. The plot also suggests that as initial height of liquid in the tank decreases, efflux time also decreases.

It can also be concluded from the plot that both sodium dodecyl benzene sulfonate anionic surfactant and mixed solution of surfactant and its counter ion are drag reducing as shown by the reduction in efflux time. However, efflux time is less in presence of the mixed solution of surfactant and its counter ion.

This is further confirmed when the exit pipe length is changed to 0.5m while keeping the dia.of tank constant at 0.3m and is shown in the following figure (Fig. 3).

It can be concluded from Fig. 2 and Fig. 3 that efflux time is the lowest in presence of mixed solutions of surfactant and counter ion and is independent of length of the exit pipe. This is further confirmed by changing the exit pipe length to 0.75m while keeping the dia.of tank constant at 0.3m and is drawn in Fig. 4.

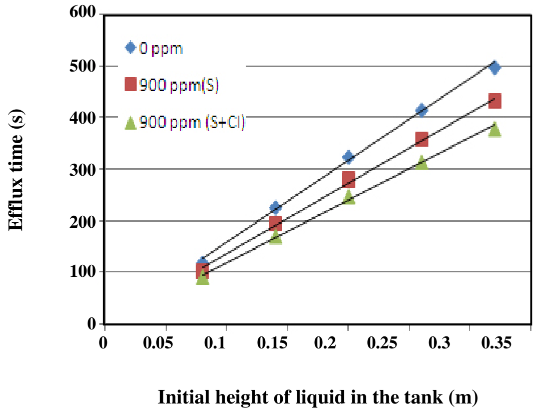

Fig. 3: Variation of efflux time with initial height of liquid in the tank (dia. of tank =0.3m, exit pipe length =0.5m).

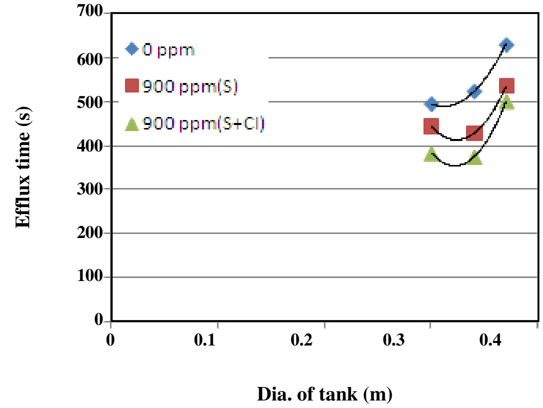

Fig. 5: Variation of efflux time with dia. of tank (length of exit pipe =0.25m, initial height of liquid in the tank =0.32m).

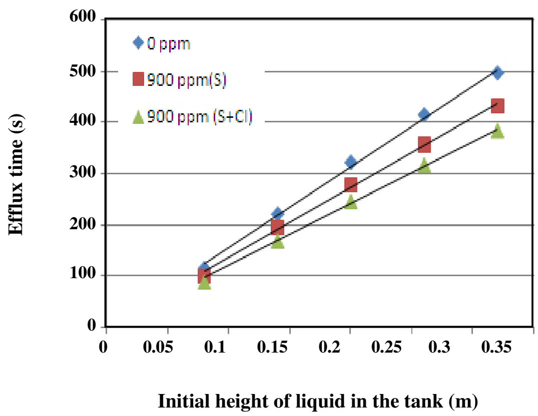

Fig. 4: Variation of efflux time with initial height of liquid in the tank (dia. of tank =0.3m, exit pipe length =0.75m).

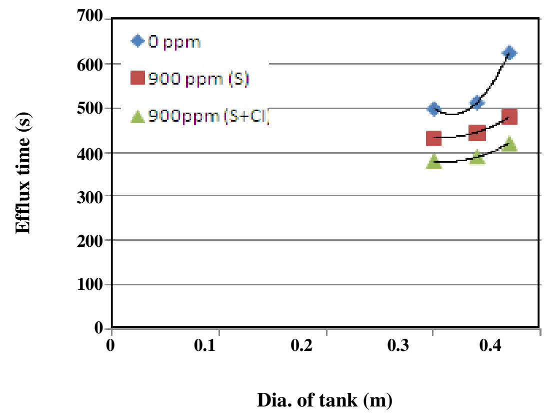

Fig. 6: Variation of efflux time with dia. of tank (length of exit pipe =0.5m, initial height of liquid in the tank =0.32m).

Variation of efflux time with dia. of the tank

The following plot (Fig. 5) shows the variation of efflux time for different dia. of tanks.

The plot suggests that as the cross sectional area increases, efflux time also increases. Since, at a fixed height of liquid in the tank, the volume of the liquid is proportional to square of the diameter of the tank, the variation in efflux time with dia. of tank is polynomial of second order. Minimum efflux time is obtained in presence of mixed solutions of surfactant and its counter ion. This is further confirmed when the exit pipe length is changed to 0.5m while keeping the initial height of liquid in the tank constant at 0.32m as shown in Fig. 6.

In this case also, mixed solutions of surfactant and its counter ion give minimum efflux time. Hence, it can be concluded that minimum concentration is not influenced by dia. of exit pipe. However, efflux time is influenced by dia. of tank.

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

The following definition used by *Santosh Kumar* and other researchers (*Santosh Kumar et al.*, 2011)[14], for defining Froude number (Fr) in gravity driven flow systems is used for calculating the Froude number.

$$Fr = \frac{V^2}{2g(H+L)} \quad (1)$$

where

$$V = \frac{D^2(H-H')}{d^2 t_{eff}} \quad (2)$$

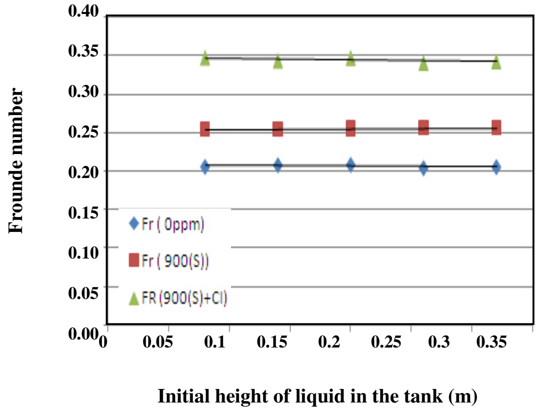

Fig. 7: Variation of Froude number with initial height of liquid in the tank, dia. of tank =0.3m, length of exit pipe =0.25m.

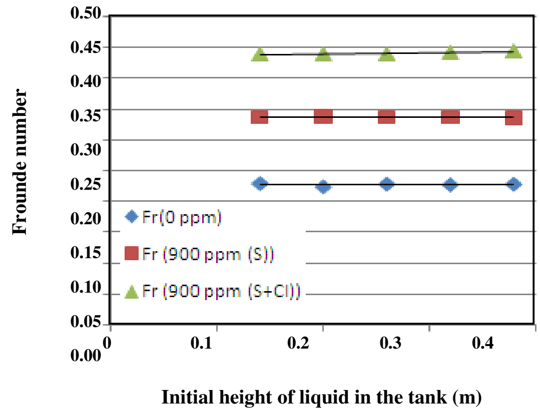

Fig. 8: Variation of Froude number with initial height of liquid in the tank, dia. of tank =0.34m, length of exit pipe =0.25m.

The following figure (Fig. 7) shows variation of Froude number with initial height of liquid in the tank.

In the figure, Froude number in the absence of drag reducing agent is designated as Fr (0ppm), Froude number in presence of 900ppm surfactant solution is designated as Fr (900(S)) and Froude number in presence of mixed solution of surfactant and counter ion is designated as Fr (900(S)+CI).

It can be seen from the figure that Froude number remains constant and is not influenced by the initial height of liquid in the tank. Froude number increases in presence of drag reducing agents and is more for the case of mixed solution of surfactant and its counter ion.

The trend is observed to be the same when the diameter of the tank is changed to 0.34m while keeping the exit pipe length at 0.25m and is shown in the following figure (Fig. 8).

It can also be concluded from the above figures (Figs. 7 & 8), even though Froude number remains constant, its value is influenced by the dia. of storage tank.

Calculation of percentage of drag reduction

Percentage of drag reduction defined by *Subbarao* and other researchers (*Subbarao et al.*, 2008)[3], is used for calculating the percentage of drag reduction and is shown in the following table (Table 2) for all the diameters of tanks considered.

From Table 2, maximum drag reduction in presence of surfactant solutions is found to be 21.4%. In presence of mixed solution of surfactant and counter ion, maximum drag reduction is 31.5% and is more than maximum of 26% reduction achieved (*Subbarao et al,* 2008)[3], using single exit pipe system, and maximum of 21% achieved for two exit pipe system (*Subbarao et al,* 2010)[9], in presence of polymer solutions. This clearly suggests mixed solutions anionic surfactant and its counter ion are better drag reducing than polymer solutions even in once through systems, but at higher concentrations.

CONCLUSIONS

Some of the conclusions of the above study are:

1- Both surfactant and mixed solution of surfactant and counter ion are drag reducing. However, mixed solution reduced drag better than surfactant solutions.

2- As the initial height of liquid in the tank decreases, efflux time also decreases.

3- Froude number remains constant during draining and increases when surfactant solutions are added. This is more in presence of mixed solutions of surfactant and its counter ion.

4- Maximum drag reduction obtained with surfactant solution is 21.4% while that of mixed solution of surfactant and counter ion is 31.5%.

Nomenclature

D	Diameter of cylindrical tank, m
d	Diameter of exit pipe, m
g	Acceleration due to gravity, m/sec^2
g_m	Modified form of acceleration due to gravity, m/sec^2
t_{eff}	Experimental efflux time, sec
V	Average velocity in the exit pipe, m/sec

Table 2: %Drag reduction for different dia.of tanks.

Dia. of tank =0.30m								
H	% Drag reduction							
	Length of exit pipe =0.25m		Length of exit pipe =0.5m		Length of exit pipe=0.75m		Length of exit pipe=1m	
	900(S)	900(S+CI)	900 (S)	900(S+CI)	900S	900(S+CI)	900S	900(S+CI)
0.32	10.3	22.6	13.2	23.8	12.9	22.5	15.3	23.8
0.26	10.7	22.6	13.9	24.3	13.7	23.4	13.1	21.7
0.20	9.7	22.6	13.8	23.7	13.7	23.6	13.1	22.8
0.14	9.7	22.2	14.1	25.1	11.8	23.5	16.4	24.4
0.08	10	23	13.4	24.4	12.2	23.5	14.5	23.6
Dia. of tank=0.34m								
	900(S)	900(S+CI)	900 (S)	900(S+CI)	900S	900(S+CI)	900S	900(S+CI)
0.38	17.5	28.4	12.3	24.6	8.5	20.9	13.1	22.3
0.32	17.9	28.4	13.3	24.0	7.3	20.8	14.2	22.4
0.26	17.6	28	12.2	24.4	5.4	19.7	15.7	22.2
0.20	18.7	28.7	13.3	24.0	4.7	21.6	14.7	22.8
0.14	17.5	27.8	13.9	25	3.7	20.7	14.2	23.1
Dia. of tank=0.37m								
0.46	14.5	21.3	23.3	32.4	21.3	31.5	20.3	31.3
0.40	14.8	21.4	22.8	32.0	20.0	31.3	19.7	30.8
0.32	15.1	20.6	23.2	32.8	20.3	31.1	19.2	30.0
0.26	15.0	20.3	22.6	32.3	20.9	30.8	19.1	29.0
0.20	15.6	21.3	22.2	31.9	21.4	31.4	19.7	29.4

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REFERENCES

[1] Hart P.W., Sommerfeld J.T., Expressions for Gravity Drainage of Annular and Toroidal Containers, *Process Safety Progress.,* **14**, p. 238 (1995).

[2] Donald D.Joye, Branden C. Barret, The Tank Draining Problem Revisited: Do These Equations Actually Work, *Can.J. Chem.Eng.*, **81**, p. 1052 (2003).

[3] Subbarao Ch.V., King P., Prasad V.S.R.K., Effect of Polymer Additives on the Dynamics of a Fluid for Once Through System, *Int.J.Fluid Mech.Res.*, **35**, p. 374 (2008).

[4] Choi K.S., Yang X., Calyton B.R., Glover E.J., Alatar M., Semenov B.N., Kulik V.M., Turbulent Drag Reduction Using Complaint Surfaces, *Proc. R. Soc. Lond.* **453**, p. 2229 (1997).

[5] Henoch C., Krupenkin T.N., Kolonder P., Taylor J.A., Hodes M.S., Lyons A.M., Peguero C., Breuer K., Turbulent Drag Reduction Using Super Hydrophobic Surfaces, 3rd AIAA Flow Conference, San Francisco, pp1-5 (2006).

[6] L.vov V.S., Pomyalov A., Procaccia I., Tiberkevich V., Drag Reduction by Micro-Bubbles-the Limit of Minute Bubbles, *Phys. Rev. lttr.*, **94**, p. 174502-1 - 174502-5 (2005).

[7] Jurban B.A., Zurigat Y.H., Al-shukri M.S., H.HAl-Busaidim H.H., The Use of Drag Reduction Agent and a Detergent for Drag Reduction in a Circulatory Vertical Flow, *Polymer-Plastics Tech. Eng.,* **45**, p. 533 (2006).

[8] G.Agulilar G., K.Gaslijevic K., Mathys E.F., Reduction of Friction in Fluid Transport: Experimental Investigation, *Revista Mexiciana De Fisca,* **52**, p. 444 (2006).

[9] Subbarao Ch.V., MallikarjunaRao K., King P., Bhasakara Sarma C., Prasad V.S.R.K., Drag Reduction by Polymer Additions in Once Through Systems, *Int.J.Fluid Mech.Res.*, **37**, p. 391 (2010).

[10] Reddy G.V.S.K., Subbarao Ch.V., Comparison of Efflux Times Between Cylindrical and Spherical Tanks Through An Exit Pipe, *Int.J.Eng.App.Sci. (IJEAS),* **3**, p. 61 (2011).

[11] Subbarao Ch.V., Comparison of Efflux Time between Cylindrical and Conical Tanks Through an Exit Pipe, *Int.J. Appl.Sci.Eng.,* **9**, p. 33 (2011).

[12] Gopal Singh P.V, Subbarao Ch.V, Venkaterswarlu P., Drag Reduction by Different Solutions of Polymers in Gravity Driven Flow, *Int.J.Appl.Eng.Res*, *Dindigul*, **1**, p. 899 (2011).

[13] Wang Yi., Yu B, L. Zakin J., Shi H., Review on Drag Reduction and Its Heat Transfer by Additives, *Adv.Mech.Eng.*, p. 1 (2011)

[14] Santosh Kumar G, SubbaraoCh.V, King P, Efflux Time for Two-Exit Pipe System, *Int. J. Appl. Sci. Eng.*, **9**, p. 277 (2011).