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Slow draining of large spherical tank under gravity

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ABSTRACT

Measurements on efflux time are performed for draining a large open spherical tank through an exit pipe, the flow in the exit pipe is assumed to be laminar. Laminar flow is maintained by using different concentrations of glycerin solutions. The experimental values are compared with the mathematical model and found to be in good agreement with the model. The model is also verified for different exit pipe lengths and different volumes of liquid in the tank. Further, the effect of addition of polyacrylamide and polythene oxide polymers on drag reduction for water as well different concentrations of glycerin solutions is contemplated. It is observed that, for the range of concentrations of polymers considered, drag reduction prevails in absence of glycerin solutions only. The optimum concentration with polyacrylamide is found to be 1.25 ppm and in case of polythene oxide, it is 10ppm. However, for the case of polymer solutions of different concentrations prepared using glycerin solutions, instead of drag reduction, drag enhancement takes place. The trend is found to be same for all volumes of liquid as well as for all exit pipe lengths. This suggests that caution has to be exercised when using polymer solutions for drag reduction in gravity driven flow systems.

Introduction

Different geometries of storage vessels will be used in chemical industries. The choice of a particular geometry depends on convenience, insulation requirements, floor space, material costs, corrosion and safety considerations. The time required for draining the liquid content from the storage vessel will be of utmost importance either due to emergency situations or to meet the productivity requirements. This time is known as efflux time as reported by Hart and Sommerfeld [1]. Literature is available for draining the contents of the cylindrical storage vessels of different diameters through restricted orifice [2,3,4]. Literature reports efflux time experiments through an exit pipe for the case of turbulent flow [5,6,7,8] as well as laminar flow [5,9] in the exit pipe. Detailed review on efflux is also available in the literature [10]. Even though majority of the industrial problems are turbulent, laminar flow is also gaining importance as in the case of flow of ink from ball point pen, flow through blood vessels and flow of a liquid from saline bottle. Present work considers time required for draining the liquid from the spherical storage vessel through an exit pipe when the flow in the exit pipe is laminar. This gives the maximum time required for draining the contents of the spherical storage vessel. Laminar flow is maintained by using an exit pipe $1.95X10^{-3}$m dia as well as different concentrations of Glycerin solutions of 1.25%, 2.5%, 5% and 10% (wt/wt).

During draining from the storage vessel through exit pipe, the liquid has to overcome frictional resistance or drag. This drag can be reduced by different methods. They are use of hydrophobic surfaces, air injection, surfactants and polymer solutions and non-Newtonian rigid fibers. Polymers and surfactants however, are more suitable as their addition yields considerable savings in energy. To achieve a given amount of drag reduction, the concentrations of surfactant solutions are much higher than that of polymers. More over, polymers are best suited for once through systems. Hence, present work considers the effect of polymer additions on reduction in efflux time. The polymers considered are polythene oxide and polyacryl amide since they are used earlier for drag reduction studies in once through systems

- Efflux time measurement for water as well for different concentrations of Glycerin solutions
- Preparation of polymer solutions of different concentrations in the presence and absence of Glycerin solutions
- Efflux time measurement of water as well as glycerin solutions in presence of both polymer solutions

The above experiments are repeated for different lengths of exit pipes while keeping the dia of storage vessel constant.

Experimental procedure:

Part A :

The equipment used for experimentation consisted of a stainless spherical tank (Fig.1) provided with a level indicator and a mild steel pipe of $1.95X10^{-3}$m dia directly welded at the bottom of the tank. A gate valve (GV) provided at the bottom of the tank served as the outlet for draining. Bottom valve was 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 valve. The drop in water level was read from the level indicator. The time was recorded for a fall in the liquid level to predetermined level just above the tank bottom. The experimental efflux time was designated as **tact**. The

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experiments were repeated and the measurements were taken to check the consistency of data. The experiments were carried out with 1.25%, 2.5%, 5% and 10% Glycerin solutions using single exit pipe length of 0.75m, 0.5m and 0.25m.

Part B :

Experimental data on efflux time were also obtained with pre-mixed polyacrylamide (PAM) of different concentrations. The stock solution of PAM was prepared by dissolving $2X10^{-3}$ kgs of polymer in $4X10^{-3}m^3$ of water. A small quantity of isoproponal was added to the solution to serve as disinfectant. The solution was stirred for 4 hours and then allowed to hydrate for 4 hours. The clear solution without any non-homogeneity was diluted suitably to prepare desired concentration of polymer solutions.

To prepare glycerin solutions containing polymer, requisite amount of glycerin is added to polymer solutions to prepare 1.25%, 2.5%, 5% and 10% glycerin solutions.

The procedure is repeated using polythene oxide (PEO) solutions as well.

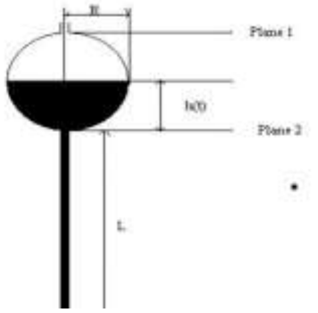

Fig.1 : Open Cylindrical tank with an exit pipe

Results and Discussion :

When a liquid is drained from a spherical tank though an exit pipe, the liquid could be completely drained from the tank which was not the case when a liquid is drained from a cylindrical tank through an exit pipe [6].

Verification of mathematical equation with experimental values:

Bird et al derived the equation for efflux time when a liquid is drained from a large spherical tank through an exit pipe for laminar flow in the exit pipe. However, the equation is applicable when the tank is completely filled with the liquid.

The following equation for efflux time is developed by the authors for arriving at the efflux time

$$teq = \frac{1}{A}\left[2R\left(H - L\ln\left(\frac{H+L}{L}\right) - \left(\frac{H^2}{2} - LH\right) - L^2\ln(1+\frac{H}{L})\right)\right] \quad (1)$$

Where R is radius of sphere, H is the height of liquid in the tank, L is the length of exit pipe, $A = \frac{\rho g D^4}{128\mu L}$, ρ is the density of liquid, D is diameter of storage vessel, μ is the viscosity of liquid, g is acceleration due to gravity.

This equation can be used for calculation of efflux time for both cases of complete filling as well as partial filling of liquid in the tank.

When experiments are performed with water, the Reynolds number is observed to fall in the transition region for all the volumes of liquid in the tank as well as at all the lengths of exit pipes. Hence, no attempt is made to check the validity of the mathematical equation with water.

Variation of efflux time with respect to volume of liquid in the tank:

While deriving the equation, (Eq.1), the fluid motion within the spherical tank is not considered. The roughness of the tank and that of the exit pipe are also neglected. The contraction losses are not accounted for. This gives rise to deviation between theoretical and experimental values.

When glycerin solution of 1.25% is drained through an exit pipe of length 0.75m, the variation of efflux time at different volumes of liquid in the tank is shown in fig.2. In the figure, **tact** indicates actual values of efflux time, while **teq** indicates the efflux time based on mathematical equation.

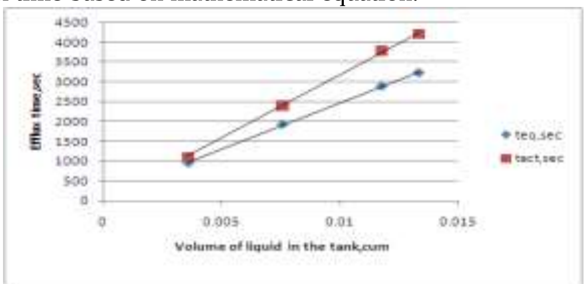

Fig.2 :Variation of efflux time with volume of liquid in the tank, exit pipe length=0.75m, glycerin concentration =1.25 Wt%

An average deviation of 21% is observed. This deviation is possibly due to neglecting the flow within the spherical tank, roughness of the tank as well as the exit pipe and contraction losses.

The trend observed to same for 2.5%, 5 % and 10% glycerin concentrations.

The flow in the exit pipe in all the cases is calculated and found to be in the laminar region only.

When the exit pipe length is changed to 0.5m, the variation of efflux time with volume of the liquid in the tank for 1.25% glycerin solution is shown in the following figure(Fig.3).

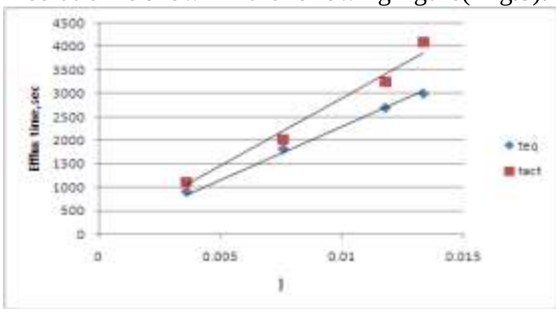

Fig 3 : Variation of efflux time with volume of liquid in the tank, length of exit pipe=0.5m Maximum deviation of 17% is observed between theoretical and experimental values

When the exit pipe length is changed to 0.25m, the trend is shown in the following figure (Fig.4).

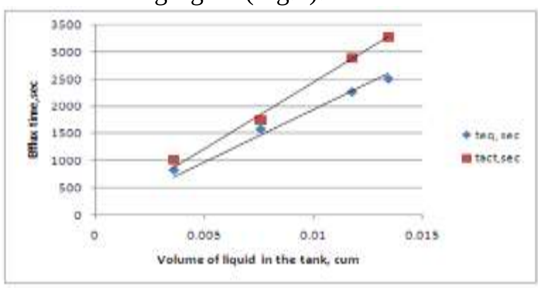

Fig.4 : Variation of efflux time with volume of liquid in the tank, Exit pipe length=0.25m Maximum deviation of 18% is observed.

Variation of efflux time with polymer concentration with water

The following plot shows the variation of efflux time in the presence and absence of aqueous solutions of polymers. The polymers used are Polyacrylamide (PAM) and polythene oxide (PEO).

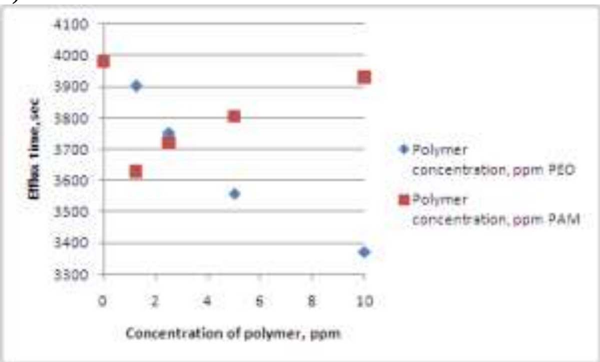

Fig.5 : Variation of efflux time with polymer concentration for 0.75m exit pipe length, Volume ofl liquid in the tank=0.13m^3

The optimum concentration (i.e minimum efflux time) is at 1.25 ppm with PAM and at 10ppm with PEO.

When the volume of liquid in the tank is changed to 0.12 cum, the variation of efflux time with different concentration of polymer solutions for both polymers considered is shown in the following figure (Fig.6)

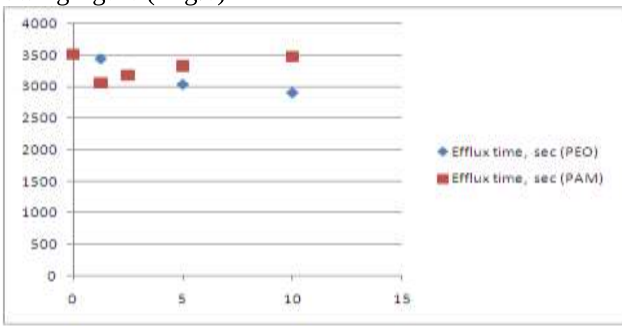

Fig. 6 : Variation of efflux time with polymer concentration, exit pipe length =0.75m, volume of liquid in the tank =0.12m^3.

In this case the also, optimum is 10ppm with PEO and 1.25 with PAM. This suggests that optimum concentration is not influenced by volume of liquid in the tank.

Variation of efflux time for glycerin solutions in the absence and presence of polymers :

In case of mixed solutions of polymer and glycerin, the variation of efflux time with different concentration of polymer is shown below for 1.25% glycerin.

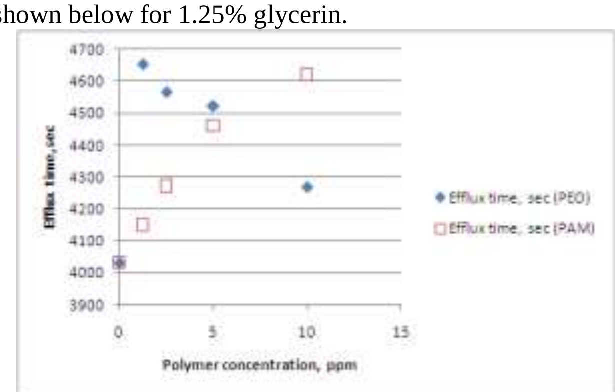

Fig. 7: Variation of efflux time for 1.25% glycerin mixed with different concentrations of polymer solutions

The plot clearly suggests that both efflux time is higher in presence of both polymers. Hence drag enhancement takes place when glycerin solutions are mixed with both the polymers.

The trend for other concentrations of glycerin mixed with polymer solutions is found to be similar.

Conclusions

Some of the conclusions of the above study are

1. The mathematical equation for efflux time gives a deviation of 17% between experimental and theoretical values
2. Drag reduction takes place in the presence of aqueous solutions of polymer. The optimum concentration with PEO is found to be 10ppm while with PAM it is found to be 1.25ppm.
3. No drag reduction is observed when glycerin is mixed with polymer solutions for laminar flow conditions in the exit pipe.

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