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Drag Reduction by Biopolymers in Gravity Driven Flow

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ABSTRACT: Experiments are conducted for determining the time required for discharge of water from a long cylindrical open container by means of vertical pipe attached at the centre of the bottom of the container. The flow in the connected vertical pipe is assumed to be turbulent. When the pipe line flow is turbulent, there is drag and reduction in drag increases the effective utilization of energy. This drag reduction can be effectively achieved by polymers. The present study is envisaged to study the effect of premixed aqueous solutions of bio-polymers namely Carboxymethylcellulose (CMC and guar gum (GG) on reducing the discharge time. The concentration of both the polymer solutions which gives less discharge time is determined. Lowest discharge time is obtained at 0.625ppm of both the polymers. With an increase in concentration of these polymers, there is an increase in discharge time which is different from what has been reported for closed flow systems. With an increase in diameter of drain pipe, % drag is reduced in the presence of aqueous solutions of polymers which is also different from what is reported in closed flow. For the same Reynolds number through the outflow pipe, the % drag reduction is different. As the diameter of drain pipe is increased, the Reynolds number also changes and there is a decrease in % drag reduction when pre-mixed polymer solutions are emptied from the container. At the same concentration of both the polymers, CMC is found to be better in the reduction of out flow time compared to Guar gum.

Keywords : Bio-Polymers, Concentration, Discharge time, Drag reduction, , Turbulent flow.

Abbreviations: GG, Guar gum, CMC, Carboxymethylcellulose.

I. INTRODUCTION

Liquids in chemical industries are stored in different containers. The container geometry is governed by many factors like insulation requirements, space etc. The time required to remove the liquid residing in the container is very important either for increasing the production rate or to take care of unexpected conditions. When a liquid is to be removed from a container, there is frictional resistance which is a combination of flow in the exit pipe, flow around the tank, roughness of the wall of the container. This resistance is more significant at the contraction point where there is a possibility of change of flow change from Laminar (in the container) to turbulent (in the pipe). All these resistances add to the increased discharge time from the container. This discharge time can be reduced by addition of minute quantities of polymer solutions [1]. The addition of these polymer solutions decreases the discharge time and hence leads to effective utilization of storage containers. Polymer solutions used for drag reduction can be categorized into rigid polymers and flexible polymers [2]. Literature reports experiments on reducing of discharge time using polyacrylamide polymer in once through system [3-5]. These solutions undergo degradation and hence it is difficult to study their dynamics in closed loop systems. Once through system is free from flow disturbances and hence better system for studying the dynamics with these polymers [6].

Earlier studies used drag reducing polyacrylamide polymer [1] for understanding the extent of drag reduction in gravity driven flow. However, polyacrylamide is very expensive. Hence, use of bio-polymers for drag reduction is contemplated [8].

The objective of the present study is to assess the performance of drag reducing rigid bio-polymers Guar gum (GG) and Carboxymethylcellulose (CMC). The reduction in discharge time is an indication of extent of drag reduction. The variables studied are height of liquid in the tank, diameter of the container, diameter of exit pipe, length of drain pipe and concentration of polymer solutions used.

II. MATERIALS AND METHODS

The apparatus used for carrying out the draining time experiments is schematically represented in Figure 1. The equipment used for experimentation consisted of known diameter open storage vessel of diameter (D) firmly placed on a wooden structure. Carbon Steel pipe of diameter (d) is used as drain pipe and this drain pipe is directly attached to the storage tank. The liquid from the tank is drained by means of a valve (GV) provided at the bottom most point of the drain t pipe. The level in the tank can be read from a transparent plastic tube attached to the tank.

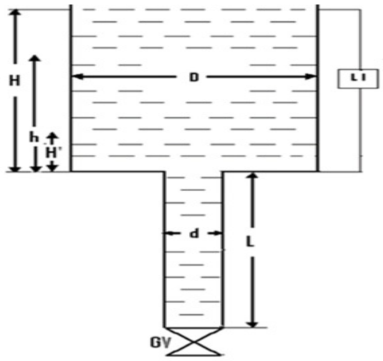

Fig. 1. Open Cylindrical tank along with drain pipe.

Before conducting the experiments on drain time, the tank and exit pipe is closed by gate valve provided to the pipe. The tank and the exit pipe are filled with water. The stop watch is started as soon as the gate valve is opened. The time required to empty the water from an initial height (Hi) to final height (H') is noted. The discharge time is designated as t_w.

The pre-mixed polymer solutions are prepared as per the procedure reported in the literature [6]. The pre-mixed polymer solutions are added to tank and exit pipe assembly and the data on drain time is generated on similar grounds for water. Each experiment on drain time is done by freshly prepared polymer solutions to ensure that there is no degradation of these polymer solutions at any point from tank to exit pipe during discharge. This discharge time is designated as t_p .

Percentage drag reduction is calculated as

$$\% \text{ Drag reduction} = 100 * \left(1 - {t_P}/{t_W}\right) \quad (1)$$

The list of variables considered in the present study are listed in table-1

Table 1 : List of variables.

S.No.	Variable	Units (m)
1.	Diameter of tank,	0.37, 0.34, 0.30 m
2.	Height of liquid in the tank,	0.50, 0.40, 0.24, 0.20m for 0.37 m dia tank 0.40,0.32, 0.24 and 0.20m for 0.34m dia tank and 0.20, 0.18, 0.15 and0.13m for 0.30 m dia tank
3.	Concentration (ppm)	0.625,1.25, 2.5 and 5
4.	Diameter of exit pipe ,m	$4*10^{-3}$ and $6*10^{-3}$m
5.	Length of exit pipe, m	1, 0.75 and 0.5

III. RESULTS AND DISCUSSION

The flow in the pipe line is calculated by the use of the following equation

To verify whether the flow is turbulent or not, Reynolds number (Re) is calculated as

$$\text{Re} = \frac{d V_{2\exp} \rho}{\mu} \quad (2)$$

d is the diameter of the drain pipe, $V_{2\exp}$ is the experimental velocity in the drain pipe, ρ, μ are the density and viscosity of the liquid respectively.

$V_{2\exp}$ is obtained using the experimentally measured data as

$$V_{2\exp} = \left[\frac{D^2}{d^2 t_{act}}\right](H - H') \quad (3)$$

Where D, d are diameters of tank and drain pipe, t_{act} is the actual drain time, H, H' are initial and final height of liquid in the tank.

The Reynolds numbers for water is calculated and found to be in turbulent flow only (Re>4000).

A. Variation of drain time with respect to height of liquid in the tank

The following plot (Fig. 2) illustrates the variation of drain time with respect to the height of liquid in the tank for 0.625 ppm polymer concentration of both the polymers.

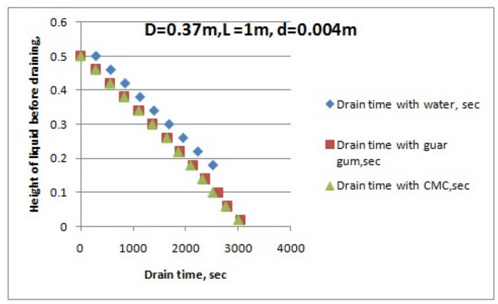

Fig. 2. Variation of drain time for a given height of liquid in the tank, Diameter of tank=0.37m, length of drain pipe= 1m, initial height of liquid in the tank=0.5m, diameter of drain pipe= $4*10^{-3}$m.

The plot suggests that as more liquid is drained from the tank, the difference in drain time for water and the polymer solutions increases and highest difference in drain time (or more drag reduction) is obtained when the liquid height reaches 0.02m. This is the height at which maximum drag reduction occurs and this is called as Virk asymptote for once through system [7].

Similar trend is observed for the cases where the liquid is drained from different initial heights.

B. Variation of drain time with concentration of polymers

Fig. 3 shows the effect of concentration on drain time for 0.37m diameter tank.

The plot suggests that the drain time is less for all the concentrations of polymer solutions used. Lowest drain time compared to water is obtained when the concentration of both the polymers used is 0.625 ppm and hence highest drag reduction is obtained for 0.625ppm concentration of both the polymers. In case of drag reduction by Polyacrylamide in gravity driven flow, the optimum concentration reported was 5 ppm [1]. The trend is found to be same for other lengths of exit pipes.

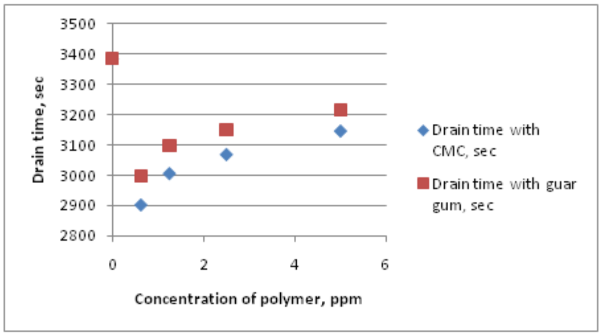

Fig. 3. Drain time with water and aqueous solutions of polymers, Diameter of tank=0.37.m, initial height of liquid in the tank= 0.5m, diameter of exit pipe= 4*10-3m, length of exit pipe =1m

When the diameter of drain pipe is changed to 0.006m, the variation of drain time is shown in Fig. 4.

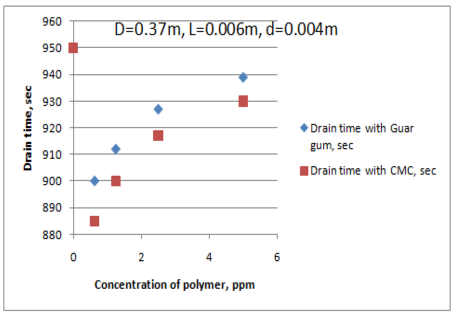

Fig. 4. Drain time with water and aqueous solutions of polymers, Height of liquid in the tank=0.37m, initial height of liquid in the tank= 0.5m, diameter of exit pipe= 6*10-3m, length of exit pipe =1m.

In this case also, draining time is lowest for 0.625 ppm CMC solutions.

C. Variation of percentage drag reduction with diameter of drain pipe

Percentage drag is calculated using equation 1 and the variation of percentage drag reduction with exit pipe diameter is shown below for 0.37m diameter tank.

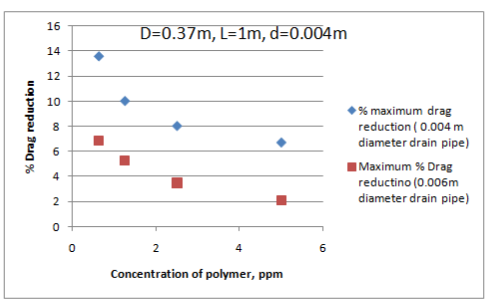

Fig. 5. Percentage drag reduction for 0.004m diameter and 0.006m diameter exit pipe for CMC solutions of varying concentrations.

The plot reveals that with increased diameter of drain pipe, there is a decrease in percentage drag reduction. Increased diameter of drain pipe means increase in Reynolds number and increased Reynolds number decreased the percentage drag reduction which is different from what has been observed in closed system [8].

IV. CONCLUSIONS

– The addition of guar gum and CMC in the concentration range decreased the draining time and hence an increase in drag reduction.
– Lowest drain time is obtained when the concentration is at 0.625ppm for both the polymers considered.
– Increased drain time decreased the percentage drag reduction which is different from what has been observed in closed forced circulation systems [8].

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Conflict of Interest. The authors do not have any conflict of interest.

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