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Characterizing Non-Newtonian Two-Phase Flow in Airlift Pumps

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Abstract **-** Experiments are performed in a recirculating two-phase flow loop using an airlift pump with an axial air injector and at different non-Newtonian rheological behaviours. This was achieved using three mixtures of Xanthan Gum (XG) and water of 0.05 %, 0.15 %, and 0.25 % by weight concentrations. Both air and liquid flow rates are recorded for the desire pump operating conditions. The pump performance found to be directly correlated with the concentrations of XG. The pump flow rates decreased as the XG concentration increased due to the decrease of slug velocity which is responsible for high lifting effect. The recorded slug velocity was found to change between 1.81 cm/s, 1.75 cm/s, and 1.7 cm/s for XG concentrations of 0.05 %, 0.15 %, and 0.25 % respectively. Also, with the increase of XG concentration, the slug length found to increase due to the formation of large slugs without many trailing small bubbles as seen in the lower concentrations' cases. As the viscosity increased for different XG concentrations, the calculated efficiency of the airlift pump found to decrease as well. This is attributed to the fact that as the liquid became more viscous, higher energy of the air is required to overcome the shear stresses acting on the liquid phase to provide lifting.

Keywords**:** Airlift Pump, Non-Newtonian, Two-phase Flow, Gas-Liquid

1. Introduction

Non-Newtonian Gas-liquid two-phase flows are found in numerous applications including food and chemicals industries, oil and gas industry and in the wastewater systems [1–3]. In these applications, airlift pumps found to be an effective fluid transport device that can handle complex multiphase mixtures and require lower energy to operate. For example; the difficulties associated in pumping slurries in wastewater treatment systems using traditional mechanical pumps due to the continuous increase in the mixture viscosity can be eliminated when using airlift pumps. This is mainly because airlift pumps don't have any moving parts responsible for shear thickening phenomenon. In the past, studies have been conducted for pumping a variety of non-Newtonian mixtures using airlift pump technology. However, most experimental setups use a basic design of an airlift pump to pump the liquids.

Ihmoudah et al. [3] investigated the effect of the rheology for non-Newtonian fluids in vertical pipe using airlift pumps. Xanthan gum and water were mixed together to create three concentrations of a non-Newtonian fluid to be used in the experimental recirculation loop. The airlift pump used to introduce air in the mixture was a single injection point in a vertical pipe to create the two-phase flow pumping. The pressure drop and void fraction was compared to numerical results which showed a good relationship. Also, Majumder et al. [4] experimentally investigated the gas hold up air/Newtonian and air/non-Newtonian flow in a vertical recirculation loop for slug flow. The airlift pump consisted of a basic single injection point into the riser to create the two-phase flow. For the non-Newtonian fluid, a mixture of water and CMC was used to create four different concentrations to be tested. The experimental results obtained was analysed using different models to develop correlations and predict gas hold up in a vertical pipe.

In a recent study conducted by Shimizu and Takagi [5], large scale airlift pumps were investigated for pumping highly viscous slurries for deep sea mining applications. The airlift pump consisted of a basic perforated tube where air was injected though the holes to be mixed with the liquid. They found that using a reliable pipe friction model for gas-slurry mixtures in high Reynolds number region can be used to improve the prediction accuracy of pump performance in large-scale airlift pumps. The experimental results were compared to a one-dimensional model used to predict the performance of the airlift pump. The results showed a good relationship between experiments and the modelling of the non-Newtonian pumping. Therefore, it can be concluded that in order to improve the performance of airlift pumps in handling non-Newtonian multiphase flows, it is important to characterize the two-phase flow behaviour in the pump riser and determine the optimum pump operating conditions [6]. Therefore, in this study the effect of two-phase flow characteristics such as the slug velocity, efficiency, liquid flow rates will be investigated on a vertical injector airlift pump.

2. Experimental Setup

Three concentrations were mixed by blending xanthan gum into 1-L of water to achieve the following concentrations 0.05, 0.15, and 0.25 wt%. Each solution was tested using a viscometer to evaluate whether the non-Newtonian fluid experienced shear-thinning or shear-thickening behaviour. The viscosity was measured at a set spindle speed which creates a shearing force by rotating the spindle within the fluid. It was observed, the measured viscosity decreased as the speed increased for all concentrations evaluated due to the non-Newtonian shear-thinning behaviour. It is also noted that the increase in concentration of XG in the mixture increases the overall viscosity of the fluid.

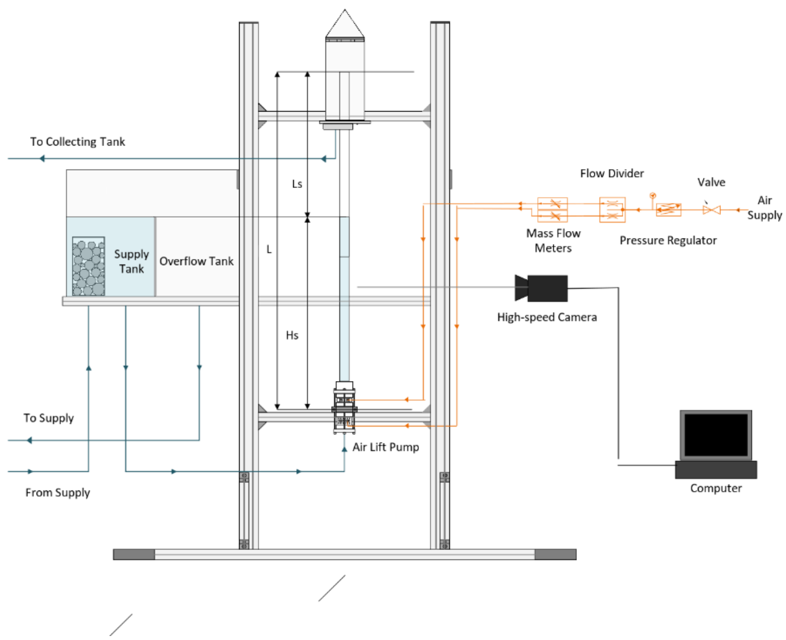


Figure 1: Schematic of the experimental setup

The schematic of the experimental setup with the airlift pump is shown in Figure 1. Liquid from a reservoir tank was pumped into a secondary supply tank (1) to maintain a constant liquid head so that the submergence ratio of the airlift pump system can be determined. The submergence ratio is calculated by dividing the static head, H_s, by the total length, L, of the pipe. For the set of air-liquid experiments the submergence ratio was set to a ratio of 70 %. The gaslift pump (2) was used to introduce the air into the liquid to create a two-phase mixture for pumping the liquid up the riser in (3). The air flow rate was controlled through mass flow controllers (MFC) for a range of 6 litres per minute (LPM) considered the minimum air flow for pumping liquid to 40 LPM as the maximum air flow. Omega mass flow controllers were used to measure the air flow with ±1.2% reading uncertainty. At the top of the setup was a collection tank that redirected the liquid to a measuring tank which had one litre increments to measure the volume of collected liquid. A human operated stopwatch was used to time the flow of water collected in the measurement tank, enabling the volumetric liquid flow rate (LPM) to be calculated with an accuracy of ± 5%. Pump performance curves were determined for each pump by varying air injection rate and recording the water flow rate. In addition, high speed imaging was utilized to analyse the two-phase flow patterns and slug velocity downstream of the airlift injector.

3. Results and Discussion

The air injection rate was varied between 6 LPM – 40 LPM while the liquid flow rate was recorded in order to characterize the performance of the gas-lift pump. The efficiency of the airlift pump at each gas injection rate was conducted to determine the most efficient point to pump the non-Newtonian mixture. Furthermore, high speed images were captured at a flow gas injection rate of 21 LPM to understand the flow pattern occurring and the slug velocity for each concentration. As shown in Figure 2, the performance curves for the pump at the three concentrations are presented. It is clear from the figure that as the concentration increases the liquid flow rate decreases which is due to the increase of viscosity and makes the liquid more difficult to pump.

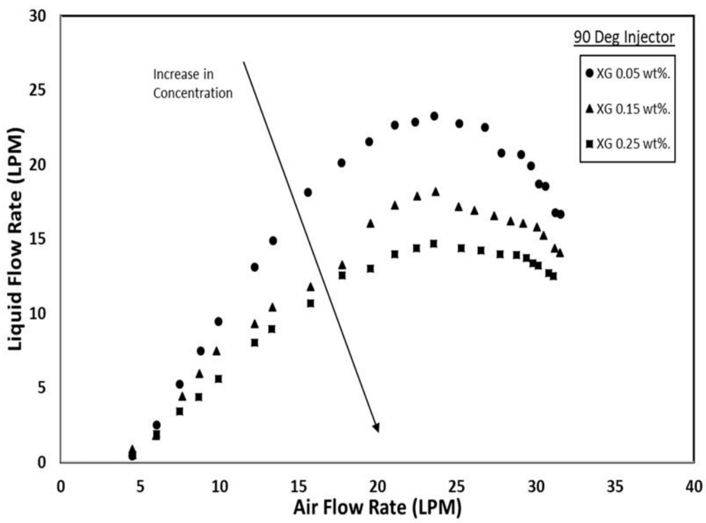


Figure 2: Performance curve of airlift pump

The efficiency of gas-lift pumps can be determined by defining the work done to move the liquid to the top of the pipe divided by the isentropic expansion work done by the gas. This efficiency equation was developed by Nicklin [7] and is as follows:

$$\eta = \frac{\rho g Q_l (L - H_s)}{P_a Q_g \ln\left(\frac{P_1}{P_a}\right)} \tag{1}$$

Using equation (1) the efficiency of each gas injection point was calculated and plotted in Figure 3. It is displayed that the decrease of efficiency occurred when the concentration for the non-Newtonian mixture increased. As the viscosity increases the concentration increases and the pumpability of the liquid decreases and so requires more work to pump the liquid.

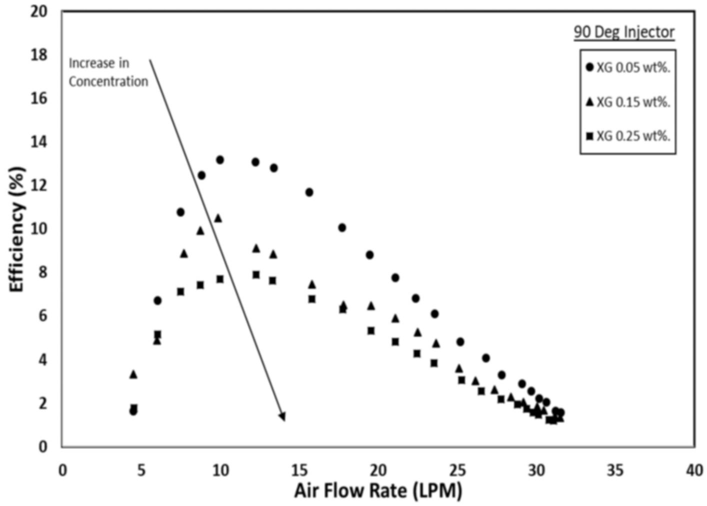
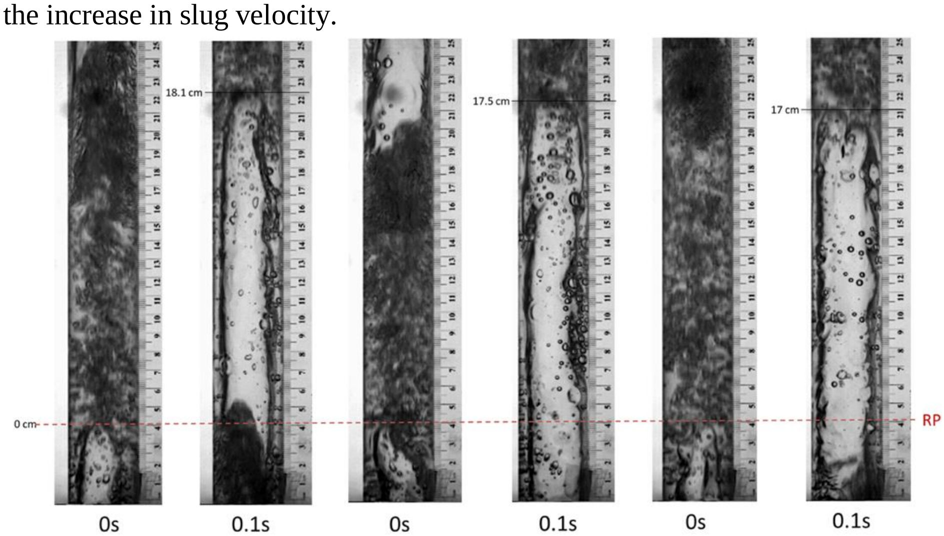


Figure 3: Efficiency curve of airlift pump

High speed images were captured at location z/D = 35 for a gas injection rate of 21 LPM for the three concentrations experimentally evaluated. Figure 4 displays that the flow pattern occurring was slug flow and displays the time sequence photos of the slug travelling in a 0.1 s time frame. It can be observed that for the lower concentration the distance travelled by the slug was greater than the two higher concentrations in the same amount of time. For the 0.05 %, 0.15 %, and 0.25 % weight concentration the corresponding velocities was 1.81 cm/s, 1.75 cm/s, and 1.7 cm/s respectively. This corresponds to the performance curves previously discussed, as the lower the concentration the higher pumping volumes were due to the increase in slug velocity.



XG 0.05 wt%. XG 0.15 wt%. XG 0.25 wt%.

Figure 4: High speed images for slug flow

4. Conclusion

This paper investigated the performance of airlift pump handling non-Newtonian fluids. It was found at higher concentrations of XG in water which is corresponding to higher viscosity values, resulted in different two-phase flow behaviour downstream of the pump injector. This includes the slug velocity, slug length and consequently affect the amount of liquid lifted. Higher concentrations of XG-water found to decrease the pump performance due to the decrease in slug velocity which is responsible for pumping action. The results also showed that at higher XG-water concentrations, the efficiency of the pump decreased as more energy is required by the injected air to overcome the higher friction drag involved.

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