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The Effectiveness of polymeric Additives on Air-Water Flow in Horizontal Pipe

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Abstract: Two phase flow through horizontal pipe was studied as a function of Polymer CONC. The fluids used in the system are water and air. The rig which is composed of 0.051m inside diameter and 5m length test Plexiglas pipehas been designed. The effects of polymeric additives over range of 0-80ppm on Flow Pattern Map, Pressure Drop, and Liquid Holdup (HL) have been experimentally observed. It was observed that, Flow Pattern Map changes with increasing of polymeric concentration, where the probability of Slug and Plug flow decreases, while Stratified and Dispersed Bubbly flow increase. On the other hand when Drag Redaction Agent(DRA concentration increased in the liquid, the pressure gradient decreased in all cases when 50 and 80ppm (DRA) were added, since where the solution viscosity drastically increases, leading to a decrease in the turbulent strength, i.e. reduction of Reynolds number and an increase in the frictional drag. Drag Reduction Percentage, DR%, increased with increasing the superficial gas velocity, Vsg, with Stratified and Annular flow, whilethe DR% decrease with increasing of Vsg with Intermittent (Plug and Slug) flow. When Polymer concentration increased in the liquid with 50 and 80ppm, the liquid Holdup increase. With all cases, HL of 80ppm is greater than HL of 50ppm, except that, HL of 50 ppm is greater than HL of 80 ppm, if the tendency to stratified flow with 50ppm more than with 80ppm polymer concentration. A modified correlation was proposed to formulate the friction factor as function of Reynolds number, additive concentration and flow pattern type. Also the pressure gradient results have been correlated based on modification of a theoretical model, the new model take into account the effect of polymer concentration on pressure gradient. The results of the presented correlation showsan acceptable agreement between the observed and predicted pressure gradient values.

Key Words: Two-Phase Flow, Polymer, Flow Pattern, and Liquid Holdup.

1. Introduction

Multiphase flow refers to the flow ofmixture, andit is of interest to thepetroleum industries, chemical process, and nuclear. Two phase gas-liquid flow has many applications in petroleum industry,it is commonly encountered in the production and transportation of oil and gas, where most oil wells produce some gas and the gas wells that flows to the surface is often accompanied by oil.Since many oil wells are located in remote sites,the long distances of fluid transportation can be a significant problem for pressure drop. The installation of pumping stations may be required due to the pressure drop in the pipeline, which leads to an increase of additional capital and operating costs. Dissolving a small amount of polymers usually a few parts per million (ppm) in water can drastically reduce the pressure drop (or friction drag) of turbulent pipe flow. This phenomenon was first discovered by Toms[1] and he has received a lot of attention afterward because of its practical use in various applications.In 1948, Toms recognized the tremendous reduction in operating pressure for turbulent flow by the addition of small concentrations of polymer. However, until this time there is little work on drag reduction in multiphase flow. Numerous experimental studies for drag reduction have been reported for single-phase flow in pipelines since DRA was difinitely discovered by Toms[1].

Drag reduction (DR) phenomena either is the increase in pumping capacity of a fluid, or a decrease in the pressure drop per unit length of transporting pipeline, which is achieved by the addition of small amounts (ppm) of polymer solution to the fluid, when it is flowing under turbulent conditions. It provides a significant reduction in energy requirements and offers several operational and practical advantages. Drag reducing agents (DRA) with high molecular weight polymers are known to reduce frictional pressure loss in turbulent flow. The used polymers should not pose any environmental threat as they are non-toxic and biodegradable, with high resistance to degradation, and high molecular weight. Potential use of drag reducing agents in the multiphase pipeline has considerable interest in the oil and gas industry due to many advantages. Currently, the main application of DRA is to increase flow rate in single phase and multiphase pipelines. The benefits of DRA use in the pipeline are reduction of operation cost (e. g. reduction of pumping power and shutdown of pumping stations), increaseof production, and reduction of pressure drop.

Many researchers have been investigated for finding the mechanism of polymeric drag reducer mixed with fluid in pipeline, but more common interpretationis reduces the turbulence in the pipeline. By reducing turbulent in the flow, polymer drag reducer directs more energy to moving additional fluid through the system. Studies have shown that the number of turbulent bursts originating at the pipe wall and strength of turbulent eddies are reduced by addition of polymeric drag reducer.It should be emphasized that polymeric drag reducer does not work by being absorbed into or coating the walls of the pipes, as some have thought, whereas it is dissolved into and becomes part of the fluid, not the pipe.

2. Two Phase Flow with DRA

It has been found by Kang et al.[2,3]that DRA has also another effect by altering flow pattern from slug to stratified flow. They have shown that the transition from stratified to the slug flow regime occurred at higher superficial liquid velocities by decreasing the slug frequency to 0 slug/minute when DRA was added. They have also reported that for slug flow, the corrosion rate by almost 50% decreased by decreasing the slug frequency with addition of DRA. Rosehart et al.[4]was studied the addition of a polyacrylamide polymeric solution in two-phase (water/air) slug flows in a 2.5-cm ID, 10.7-m long pipelines and indicated that slug translational velocity was unchanged and the slug frequency decreased at higher polymer concentrations.Greskovich and Shrier[5] have studied the effect of DRA on pressure drop in two-phase (water/air and kerosene/nitrogen) flows in 3.8-cm I.D. pipelines. The pressure drop reduction of up to 50% and 45% in water/air flows was achieved in plug flow and slug flow regimes with addition of 50 wppm DRA. Whereas in kerosene/nitrogen flows, the pressure drop reduction for slug flow was obtained up to 29% with same amount of DRA. Sylvester et al.[6] studied the effect of liquid flow rate and gas flow rate on drag reduction in horizontal natural gas–hexane pipe flow in three different diameter (1, 2 and 3 in.). Drag reduction of 34% were obtained. It was found that drag reduction increased with decreasing gas rate. Al-Sarkhi and Hanratty[7] found that the injection of a concentrated drag reducing polymers into an air–water in a 9.53 cm pipe changed an annular pattern to a stratified by destroying the disturbance waves in the liquid film. Drag reduction of 48% were realized. In a following study in a 2.54 cm pipe, Al-Sarkhi andHanratty[8] observed similar results and obtained drag reduction as high as 63%. Soleimaniet al.[9] studied experimentally the effect of drag reducing polymers on pseudo-slugs-interfacial drag and transition to slug flow. They revealed that the transition to slug flow is delayed by drag reducingpolymers and the pressure drop can increase or decrease when polymers are added.Al-Sarkhi and Soleimani[10] conducted a series of experiments to investigate the effect of drag reducing polymer on two phase flow pattern in a horizontal 2.54 cm pipe. The characteristics of two phase flow with and without drag reducing polymers were described. It is noted that the interfacial shear stress decreases sharply by adding polymers and flow pattern map is changed. Studies of the effect of the drag-reducing polymer on frictional losses have been made by Rosehartet al.[11] and by Otten and Fayed[12] for bubbly and plug flows. Kang et al.[13] studied the influence of an additive (which is not identified) on three-phase flow (oil, water and carbon dioxide). They found a drag reduction of 35% at the two highest superficial gas velocities that were studied, USG = 13, 14 m/s. A review of work on this area by Manfieldet al.[14] concludes that understanding of the influence of drag-reducing polymers on multiphase flows is not satisfactory.Sarkhi and Abu-Nada[15] have investigated the effect of drag reducing polymer on annular flow pattern in 0.0127 pipeline. The maximum drag reduction of 47% with concentration of only 40 wppm in the pipeline was observed. The result showed a maximum drag reduction that is accompanied (in most cases) by a change to a stratified pattern for which the concentration of drops in the gas phase is zero or close to zero.

3. Experimental Work

A closed circulating loop system was designated to ensure studying both DR efficiency and two-phase flow behavior by measuring severaldata (Airand Waterflow rates) forfinding flow pattern, pressure drop and liquid hold up. The rig is composed of (5 m) long and (0.051m) inner diameter of Plexiglas pipeline in order to pointing the patterns, water pump, air compressor, water flow meter and gas rotometer. The phase of liquid is pumped from its tank (1m³) into the pipe, and the gas is supplied by the compressor and it mix with the liquid phase forming the loop as shown in the figure (1). At pressure of 14.7 psi and temperature of 30^o c, laboratory measurements have been done to measure the density and viscosity of the solution (air, water and polymer) as shown in Table (1)

Table (1):Fluid Properties.

Substance	ρ kg/m^3	μ kg/m.sec
Liquid (0 ppm)	1000	0.001
Liquid (80 ppm)	1050	0.0012
Gas (air)	1.22	0.00002

Summary of Test Procedure

The water soluble Polymer, Xanthan gum (XG) with high molecular weight was acquired from North Oil Company. Its dilute solution was initially prepared with 2%wt CONC. Thus 10 gram of corresponding XG was placed in a one liter conical flask and mixed with 750 mile literwater under laboratory temperature. The container was placed in an electrical shaker at 100 rpm. The shaker was used instead of stirring device to avoid polymer degradation, hence the shaker has no sharp edge that could expose the polymer to high shear force. Flow pattern, pressure drop, and liquid holdup are measured using the following standard test procedure:-

1. The gas flow rate is set by adjustingthe gate valve which located at upstream of the flow meter.
2. The liquid flow rate is set by adjusting the gate valve and noting the rate indicator on the flow meter.
3. After the flow pattern is visually observed the following parameter are recorded:
   - Flow pattern type.
   - The liquid and gas flow rate.
   - The pressure drop at the ends of test (by using U-manometer with water as metering fluid).
   - Liquid holdup by closing the two electric valves in the same time.
4. The gas flow rate is changed and steps 1-3 are repeated.
5. The polymer concentration is changed and steps 1-4 are repeated.

The percent drag reduction is then determined by measuring the corresponding pressure drop in a test section of 5m long of dilute polymer solution, at the same flow rate, using the following equation

$$\%\mathrm{DR} = \frac{\Delta p_{\mathrm{untreated}} - \Delta p_{\mathrm{treated}}}{\Delta p_{\mathrm{untreated}}} * 100\%$$

4. Results and Discussion

This section will cover the discussion of polymer additives of concentration (0, 50, and 80 ppm) on Flow Patterns Map and its transition, Pressure Drop, and Liquid Holdup. Also we will discuss the effects of gas and liquid flow rates on Pressure Drop and Liquid Holdup. The range of superficial velocity of gas and liquidis between(0.27 – 1.36 m/s) and (0.14–3.4 m/s) for gas and liquid respectively. We can conclude the following:

The effect of polymer concentrations on flow patterns map.

Flow pattern map changes with increasing of polymeric concentration (0, 50, and 80 ppm),as shown in figures (2, 3, and 4 respectively),illustrated that the probability of Slug and Plug flow decreases, while stratified and Dispersed Bubbly flow increase, where,the slug frequency and the height of the liquid film decrease with increasing of polymer concentration. The apparent of above behavior indicates that the polymeric additives will increase liquid density, viscosity and liquid stability.

The effect of liquid and gas flow rate on pressure gradient

In general, withall concentrations of polymer0, 50, and 80ppm, figures (5, 6, and 7)respectively show that the pressure gradient of simultaneous flow of air-water in pipe is increased with increasing of liquid superficial velocity (0.14, 0.82, 1.63, 2.45, and 3.4 m/s).This is due to the fact that the height of the liquid film increases with increasing superficial liquid velocity also due to the increasing of frictional force. As instance, the pressure gradient at 0 ppm of DRA increased from196 to 368 Pa/m for superficial liquid velocity of 0.82 and 1.22 m/s respectively at superficial gas velocities of 0.82 m/s.At the same time increasing of gas superficial velocity (0.27 to 1.36 m/s), the pressure gradient increase due to the increasing of frictional force.On the other hand, the pressure gradient at 0 ppm of DRA increased from196 to 296 Pa/m for superficial gas velocity of 0.82 and 1.36 m/s respectively at superficial liquid velocities of 0.82 m/s. it is clear from the data that the liquid is more effect on pressure gradient.

The effect of polymer concentrations on pressure drop

Figures (7a, through11a) show a plots of the pressure gradient versus superficial gas velocity at a superficial liquid velocity of (0.14through 3.4m/s respectively), for appropriate CONC (0-80ppm). The corresponding effectiveness, DR%,are shown in Figures(7b, 8b, 9b, 10b, and 11b respectively). The additive of DRA led to decrease the pressure gradient in the air-water

system. The results showed that (DR%)increases as the polymer concentration increases due to an increase in the number of available polymer molecules. However, as the polymer concentration increases further, the solution viscosity drastically increases, leading to a decrease in the turbulent strength, i.e. reduction of Reynolds number and an increase in the frictional drag. In addition, there can be a temporary loss of polymeric drag reducing ability if the solutions are badly sheared, with plug and slug flow, because the forces that linkage polymer molecules together are apparently overcome with shear effects and these molecules going to break down rapidly to smaller particles which have little drag reducing ability.
It can be seen from all Figures, 7a to 11a, that the pressure gradient decreased in all cases when 50 and 80ppm DRA were added in the system, where the polymer concentration of 80 ppm was more effective in reducing the pressure gradient for all cases. Figures 7b to 11b, show the effectiveness of polymer, DR%, with 50 and 80ppm additives, the maximum DR% about 22 % was achieved with Vsl=0.14 m/s and Vsg=0.82 m/s at 80ppm, where the average DR% is about 14%at 80ppm with all range of liquid and gas superficial velocities. The maximum DR% about 17 % was achieved with Vsl=0.82 m/s and Vsg=0.82 m/s at 50ppm, while the average DR% is about 8% with 50ppm at all.

When Vsl is 0.14,at Vsg less than 0.82 m/s, stratified flow was observed, and with Vsg greater than 0.82 m/s intermittent (plug or plug and slug)flow pattern was observed. It can be seen from figure 7a that the pressure gradient decreased in all cases when 50 ppm DRA was added in the system. At superficial gas velocities of 0.27, 0.82 and 1.36 m/s, the pressure gradient decreased from 56.4 to 51.5, 147 to 130 and from 221 to 211 Pa/m respectively. It can be seen from Figure 7b that these correspond to DR% of 8.7%, 12%and 4.4% respectively. Increasing the DRA concentration to 80 ppm indicates that the DRA was more effective in reducing the pressure gradient for all cases. At superficial gas velocities of 0.27, 0.82 and 1.36 m/s, the pressure gradient decreased from 56.4 to 49, 147 to 115 and from 221 to 196 Pa/m respectively. The DR% at these velocities was 13%, 22% and 11% respectively. Generally, when Vsl is 0.82, figure 8b, the same profile is observed, where the maximum DR% of 50 & 80ppm are 17% & 19 respectively. At superficial gas velocities greater than0.82, the DR% was decreased, where, it has been observed that in the transition from stratified to plug and slug flow pattern, a large number of waves are present and the liquid film begins to be unstable and to spread around the pipe. Therefore, the DR% in this case will reduce, where the degradation of polymer increased with increasing of gas interference between the liquid and polymer mixture.

Figures 9a and 9b show equivalent plots for a superficial liquid velocity of 1.63 m/s. with 50ppm,stratified flow occurs at Vsg of 0.27 m/s,At Vsg of 0.54 m/s, Plug flow is observed, slug flow is noticed atVsg of 0.82 to 1.36 m/s.It can be seen from Figure 9a that the pressure gradient increased from 287 to 502 Pa/m with an increase of the superficial gas velocity from 0.27 to 1.36 m/s. It is seen from Figure 9a that increasing DRA concentration to 50ppm reduces the pressure gradient at all superficial gas velocities.The pressure gradient decreased from 306 to 287 Pa/m and from 564 to 502 Pa/m at Vsgof0.27 and 1.36 m/s respectively. It is seen from Figure 9b that these correspond to DR% of 6.4% and 11%, respectively.Further increasing DRA concentration to 80 ppm was accompanied with more reduction in the pressure gradient.The pressure gradient decreased from 306 to 250 Pa/m, from 417 to 343 Pa/m, and from 564 to 490 Pa/m at superficial gas velocities of 0.27, 0.82 and 1.63 m/s respectively. The effectiveness at these velocities was 18%, 18% and 13% respectively.

When Vsl is 2.45, at Vsg less than 0.82 m/s, dispersed bubbly flow was observed, and with Vsg greater than 0.82 m/s annular flow pattern was observed. It can be seen from Figure 10a that the pressure gradient decreased in all cases when 50 ppm DRA was added in the system. At superficial gas velocities of 0.27, 0.82 and 1.36 m/s, the pressure gradient decreased from 564 to 515, 711 to 637 and from 833 to 733 Pa/m respectively. It can be seen from Figure 10b that these correspond to DR% of 8.7%, 10% and 9.8% respectively. Increasing the DRA concentration to 80 ppm indicates that the DRA was more effective in reducing the pressure gradient for all cases. At superficial gas velocities of 0.27, 0.82 and 1.36 m/s, the pressure gradient decreased from 564 to 490, 711 to 588 and from 833 to 711 Pa/m respectively. The DR% at these velocities was 13%, 17% and 15% respectively. With transition from dispersed bubbly flow to slug flow pattern, the degradation of polymer increased, therefore, the DR% in this case decrease. Figures 11a and 11b show plots for a superficial liquid velocity of 3.4 m/s. It can be seen from Figure 11b that the DR% of 50 & 80ppm decreased from 8.8% to 7.5 and from 3.5 to 8.5respectively when the flow is dispersed bubbly flow with an increase of the superficial gas velocity from 0.27 to 1.09 m/s, then with annular flow, the DR% increased from 3.5% to 8.5% and from 7.1% to 9.5%, for 50 and 80ppm respectively, with increasing of Vsg from 1.09 to 1.36 m/s. where the degradation of polymer decrease with annular flow.

The effect of Polymer concentration non liquid holdup

Figures (12through 16) represent the relationship between liquid holdup, HL, and Vsgwith Vsl ofa valid rang. When Polymer concentration increased, the liquid Holdup increase in all cases, due to drastically increasing of solution viscosity and increasing the density. With relatively low Vsl, 0.14m/s for 50 and 80ppm. Figure 12 showed that the stratified flow was rapidly increased at Vsg from 0.27 to 0.82 m/s, and from 1.09 to 1.36 m/s intermittent (plug or plug and slug) flow pattern was also observed. In general, liquid holdup of 80ppm polymer is greater than liquid holdup of 0, and 50 ppm for all values of Vsg, (0.27, 0.54, 0.82, 1.09, and 1.36m/s).With increasing liquid superficial velocity to 0.82, figure 13, at 50ppm the stratified with Vsg of 0.27 to 0.54 is stronger than stratified with 80ppm. Therefore, HL of 50ppm polymer concentration is greater than HL of 80ppm when Vsg are 0.27, and 0.54 m/s, where the degradation of polymer increased with increasing of gas interference between liquid and polymer mixture, then with Vsg, 0.82, 1.09, and 1.36 m/s,HL of 80 ppm is return greater than HL of 50 ppm, where the flow is Intermittent flow with 50 and 80ppm of polymer. When Vsl is 1.63m/s, Figure 14, with all values of Vsg, HL of 50 ppm is greater than HL of 80 ppm, where, at this value of Vsl, the flow with 50ppm is more tendency to stratified flow than with 80ppm polymer concentration. Figure 14 and Figure 16, with Vslof2.45and 3.4 m/s, the flow pattern is almost dispersed bubbly flow with 50 and 80ppm, therefore, HL of 80 ppm is greater than HL of 50 ppm with most values of Vsg values, but with relatively small differences.

5. Proposed model

It has been proposed by Duckler and Hubbard[16]that the total pressure drop in two-phaseflow is assumed to be given by equation (1) which requires knowledge of the liquid holdup experimentally:

$$\left(\frac{\Delta p}{\Delta l}\right) = \frac{(4 f_m \rho_m v_{ns}^2)}{(2 g_c D H L_l^n)} \qquad (1)$$

Where:

$$\rho_m = \rho_l H_l + \rho_g H_g \qquad (2)$$

$$v_{ns} = v_{sl} + v_{sg} \qquad (3)$$

Experimental data revealed that, in slug and bubble flow regimes, Equation (1), could represent the experimental data, provided that the value of n is chosen to be 0.75, and$f_m$is given by the following equation:

$$f_m = 0.1011 R_e^{-0.25} \qquad (4)$$

Where:

$$R_e = \frac{\rho_m v_{ns} D}{\mu_m} \qquad (5)$$

$$\mu_m = \mu_l H_l + \mu_g H_g \qquad (6)$$

$$H_g = (1 - H_l) \qquad (7)$$

In order to take into account the effect of polymer concentration on drag reduction, we haveproposedthe pressure gradient and friction factor by the following expressions:

$$\left(\frac{\Delta p}{\Delta l}\right) = \frac{4 f_m \rho_{ns} v_{ns}^2}{2 g_c D \lambda_l^{(1+\left(\frac{C}{1000}\right))}} \qquad (8)$$

$$f_m = 0.1011 R_e^{-\left(0.155+\frac{C}{4000}+a\right)} \qquad (9)$$

In which:

$$R_e = \frac{\rho_{ns} v_{ns} D}{\mu_{ns}} \qquad (10)$$

$$\rho_{ns} = \rho_l \lambda_l + \rho_g \lambda_g \qquad (11)$$

$$\mu_{ns} = \mu_l \lambda_l + \mu_g \lambda_g \qquad (12)$$

$$\lambda_l = \frac{v_{sl}}{v_{sl} + v_{sg}} \qquad (13)$$

Where, (c), is the polymer concentration in ppm, and (a), is a constant referee to flow pattern type, where (a) equal to (-0.03, 0.01, 0) for stratified, annular, and other flow pattern types respectively. As shown in figures 17, 18, and 19, the new model shows good agreement with new sets of experimental data obtained under completely different operating conditions.

6. Conclusion

The flow pattern map showed a significant change with polymer additive, where, with increasing the polymer concentration in liquid the probability of slug and plug flow will decrease, while stratified and dispersed bubbly flow increase. With all concentrations of polymer 0, 50, and 80ppm, the pressure gradient of simultaneous flow of air-water in pipe is increased with increasing of liquid and gas superficial velocity. Pressure gradient decreased in all cases when 50 and 80ppm DRA were added in the system, where the polymer concentration of 80 ppm was more effective in reducing the pressure gradient for all cases. Drag Reduction Percentage, DR%, increased with increasing the superficial gas velocity, Vsg, with Stratified and Annular flow, while the DR% decrease with increasing of Vsg with Intermittent (Plug and Slug) flow. When Polymer concentration increased in the liquid with 50 and 80ppm, the liquid Holdup increase. With all cases HL of 80ppm is greater than HL of 50ppm, except that, HL of 50 ppm is greater than HL of 80 ppm, if the tendency to stratified flow with 50ppm more than with 80ppm polymer concentration. The results of the correlation showed acceptable agreement between the observed and predicted pressure gradient values.

Nomenclature

ID=Insider pipe diameter, m
Δp=Pressure drop, Pa
Δp/L=Pressure gradient, Pa/m
HL=Liquid Holdup
Hg=Void fraction
λ_l= No slip holdup
Vsl=Liquid superficial velocity, m/s
Vsg= Gas superficial velocity, m/s
Re =Reynold's number
c=Polymer concentration, ppm
f=Friction factor
L=Length, m
μ= Fluid viscosity, kg/m.
ρ=Fluid density, kg/m
DRA =Drag Reduction Agent
Ppm =Parts per million

Subscripts

G = Gas phase
l =Liquid phase
m =Mixture
ns = no slip
s = Superficial

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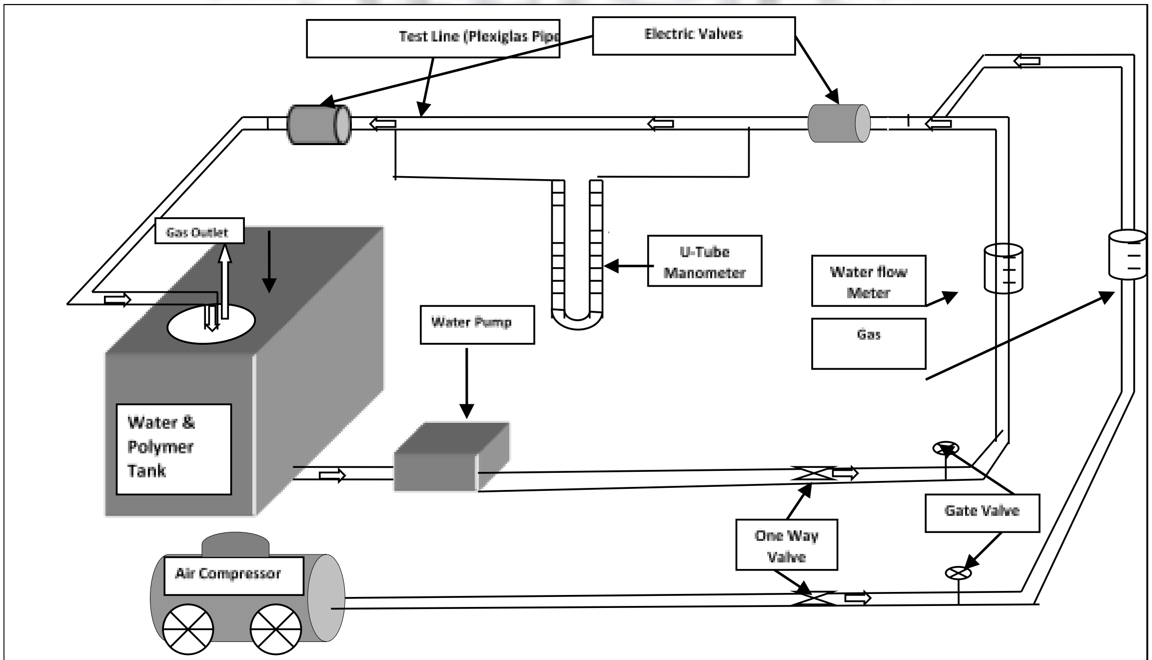

Fig. 1 Two-Phase Flow Loop

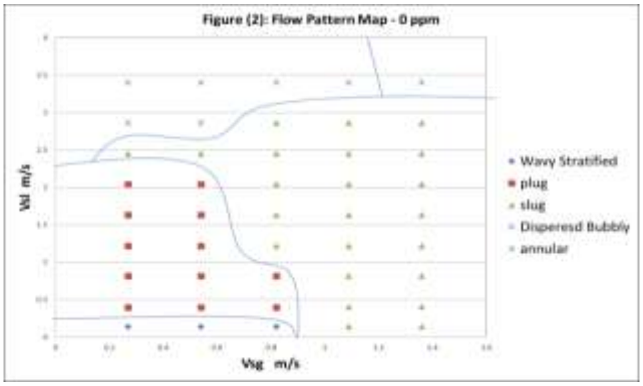
Figure (2): Flow Pattern Map - 0 ppm

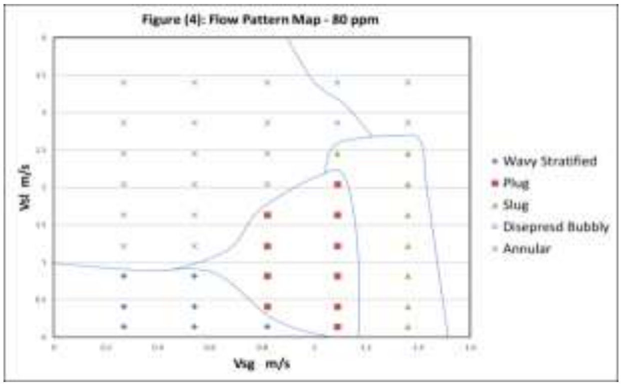
Figure (4): Flow Pattern Map - 80 ppm

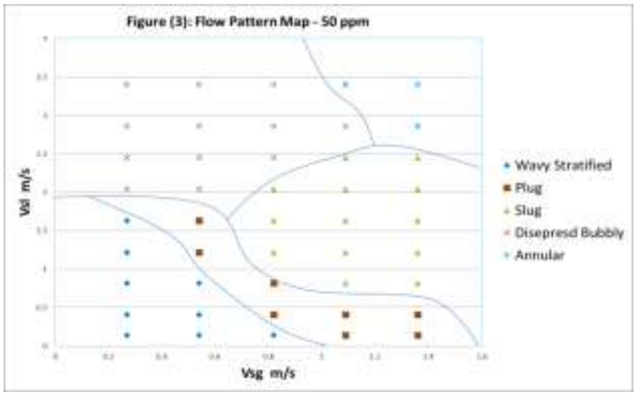
Figure (3): Flow Pattern Map - 50 ppm

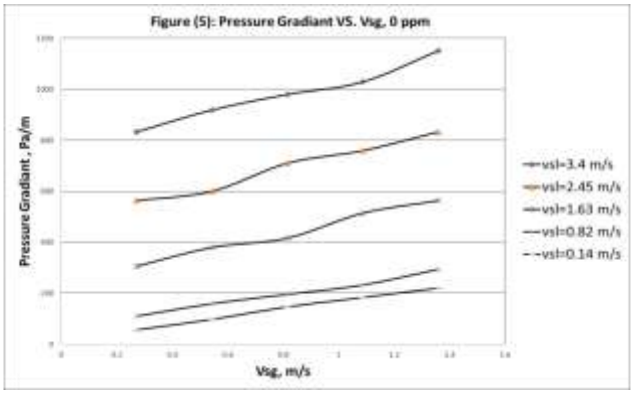
Figure (5): Pressure Gradiant VS. Vsg, 0 ppm

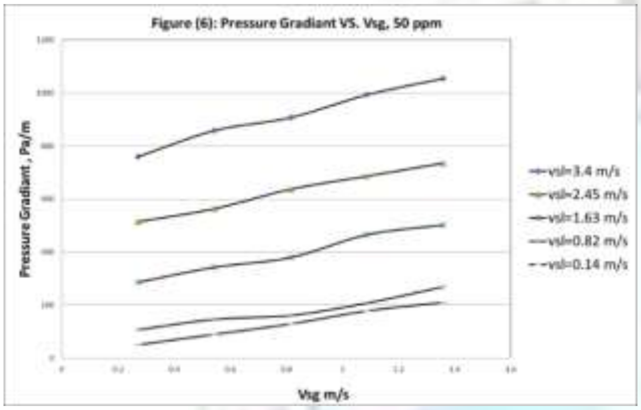
Figure (6): Pressure Gradiant VS. Vsg, 50 ppm

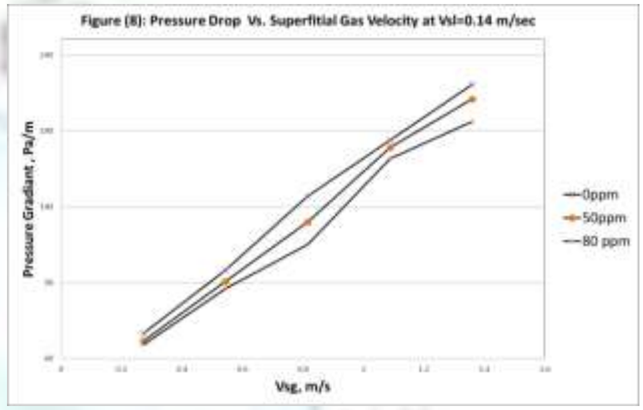
Figure (8): Pressure Drop Vs. Superfitial Gas Velocity at Vsl=0.14 m/sec

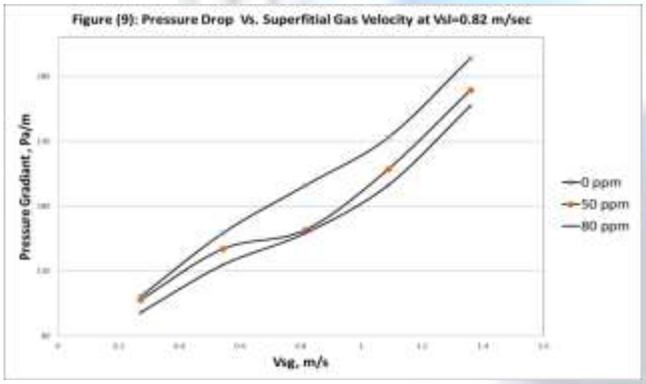
Figure (9): Pressure Drop Vs. Superfitial Gas Velocity at Vsl=0.82 m/sec

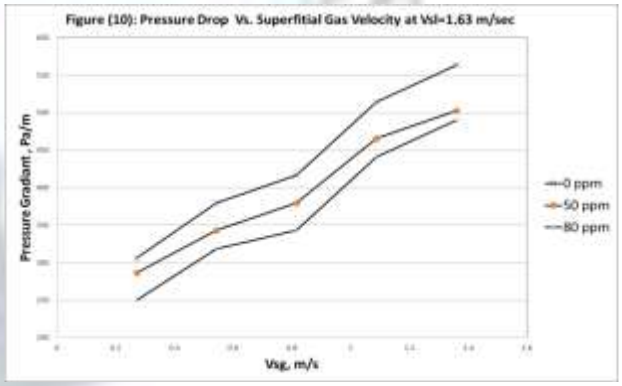
Figure (10): Pressure Drop Vs. Superfitial Gas Velocity at Vsl=1.63 m/sec

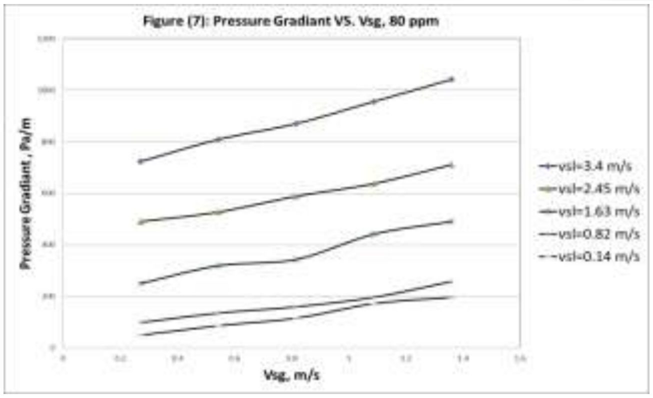
Figure (7): Pressure Gradiant VS. Vsg, 80 ppm

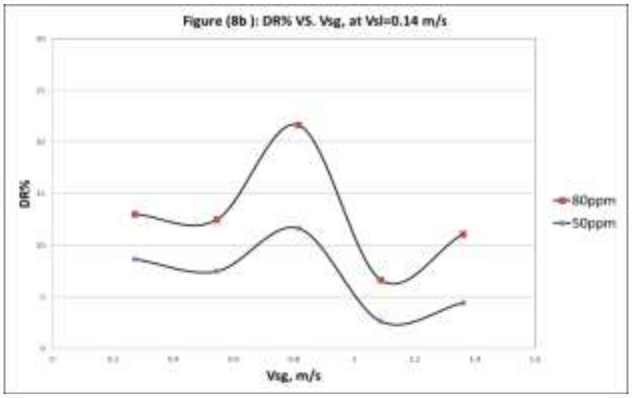
Figure (8b): DR% VS. Vsg, at Vsl=0.14 m/s

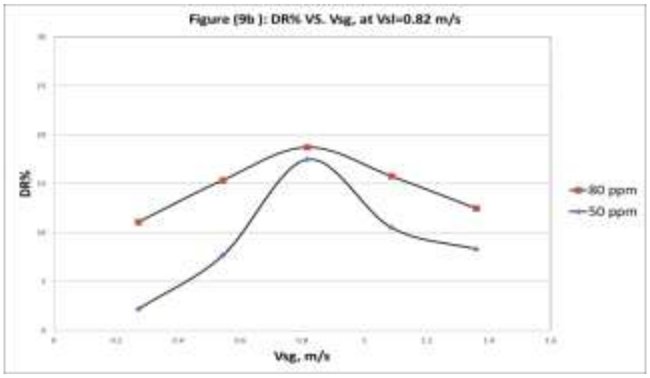
Figure (9b): DR% VS. Vsg, at Vsl=0.82 m/s

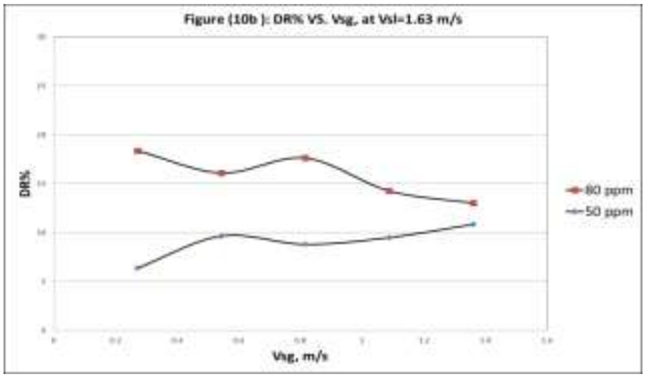
Figure (10b): DR% VS. Vsg, at Vsl=1.63 m/s

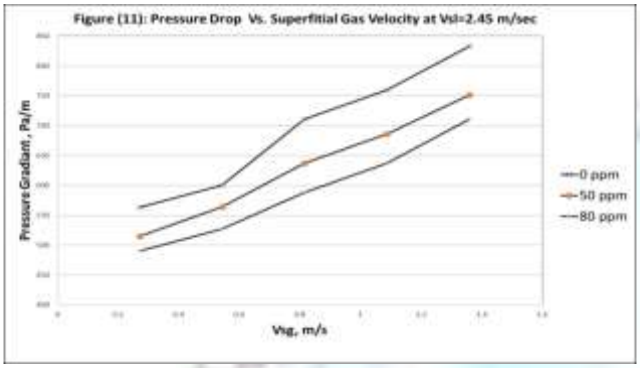
Figure (11): Pressure Drop Vs. Superfitial Gas Velocity at Vsl=2.45 m/sec

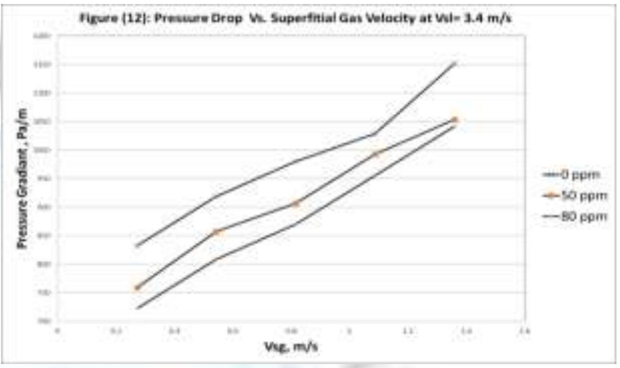
Figure (12): Pressure Drop Vs. Superfitial Gas Velocity at Vsl= 3.4 m/s

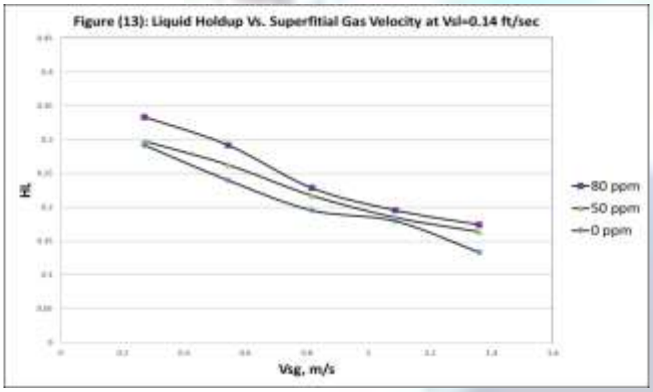
Figure (13): Liquid Holdup Vs. Superfitial Gas Velocity at Vsl=0.14 ft/sec

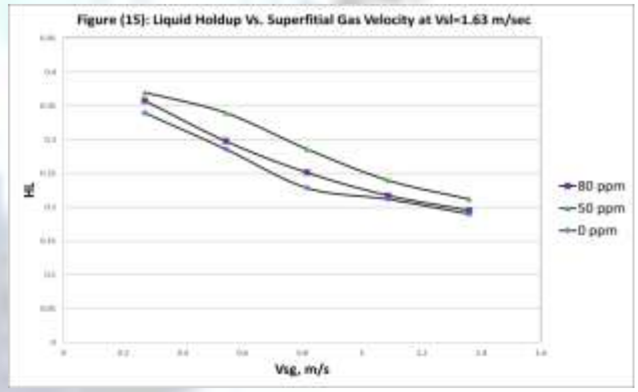
Figure (15): Liquid Holdup Vs. Superfitial Gas Velocity at Vsl=1.63 m/sec

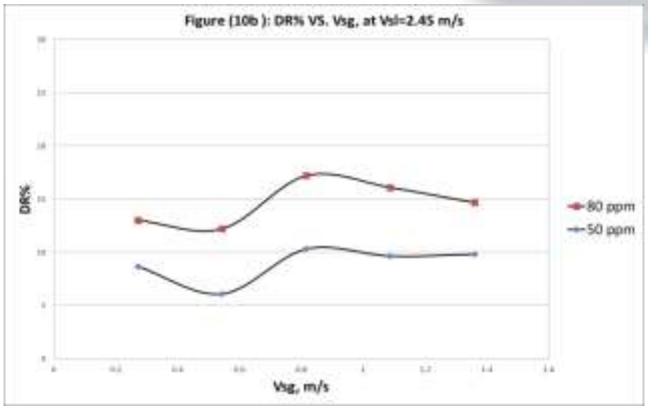
Figure (10b): DR% VS. Vsg, at Vsl=2.45 m/s

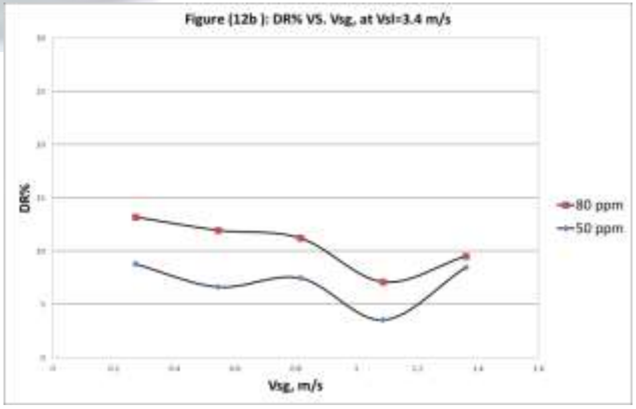
Figure (12b): DR% VS. Vsg, at Vsl=3.4 m/s

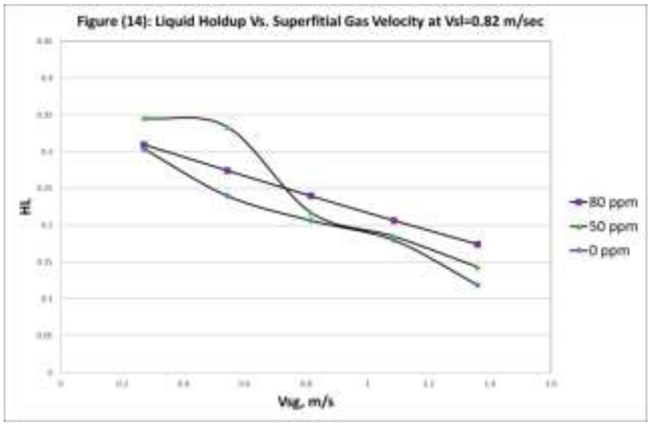
Figure (14): Liquid Holdup Vs. Superfitial Gas Velocity at Vsl=0.82 m/sec

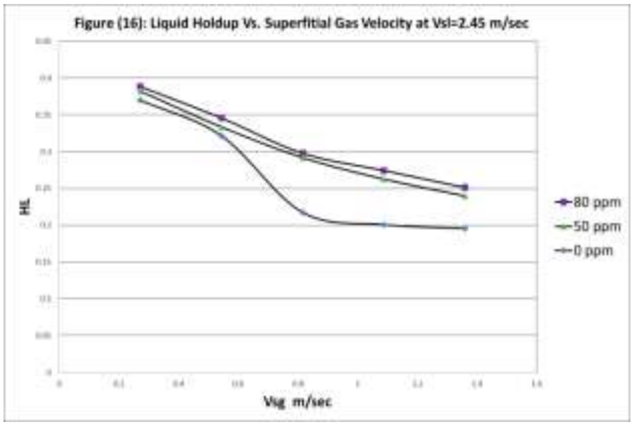
Figure (16): Liquid Holdup Vs. Superfitial Gas Velocity at Vsl=2.45 m/sec

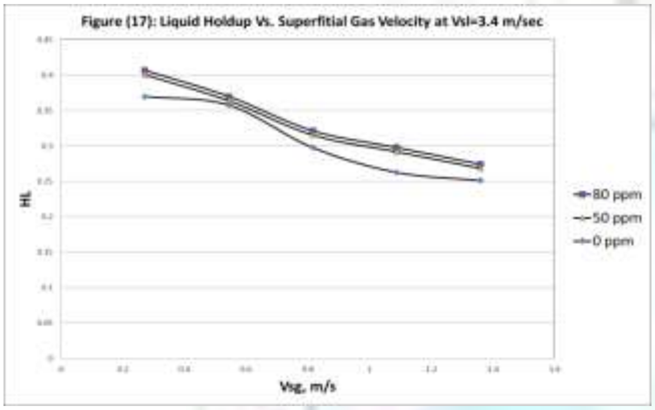
Figure (17): Liquid Holdup Vs. Superfitial Gas Velocity at Vsl=3.4 m/sec

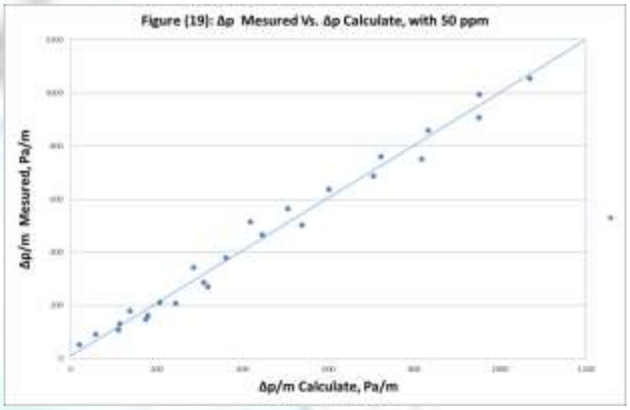
Figure (19): Δp Mesured Vs. Δp Calculate, with 50 ppm

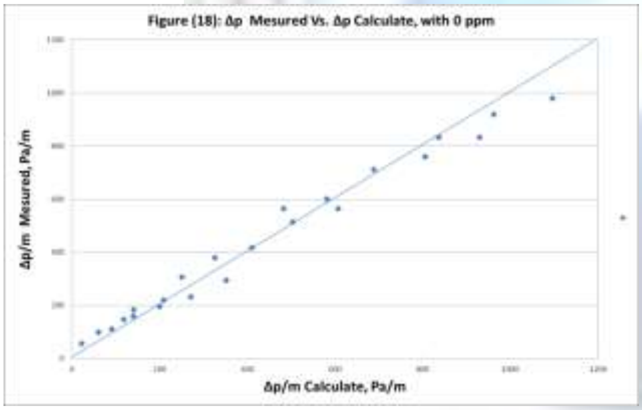
Figure (18): Δp Mesured Vs. Δp Calculate, with 0 ppm

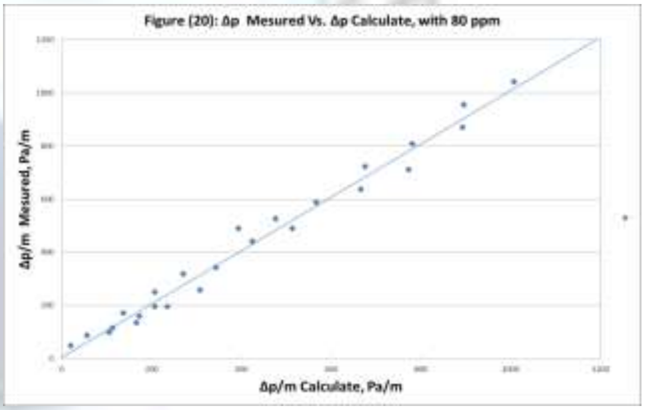
Figure (20): Δp Mesured Vs. Δp Calculate, with 80 ppm