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Experimental Investigation of Three Phase Flow (Liquid-Gas-Solid) in Horizontal Pipe

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Abstract: -The study of three phase flow in horizontal and vertical pipe are important phenomena in oil and gas industry due to extracting process involve liquid, solid and gas phase. The effect of the particle amount, the discharge of gas and liquid have investigated experimentally on pressure distribution in horizontal pipe have been studied in this work. The work carried out for horizontal pipe with outer diameter (3.175 cm). A spherical stainless steel has used as solid particle. Air and water have used as gas and liquid phase respectively. Three different amount of gas discharge used namely 8.34, 16.67and 25 L/min. As well as, three different amount of liquid discharge used which are, 25, 30 and 35 L/min. It has found that the pressure distribution along horizontal pipe decrease with increase the air, liquid and particle amount.

Key words: **Particle, multiphase flow, gas-sold, three phase flow, horizontal pipe, pressure fluctuation**

I. INTRODUCTION

Nowadays, the needs to further investigation for multi-phase flow have increased due to wide variety of application such as oil-gas industry, chemical industry and energy consumption etc. A numerous experimental and numerical studies have carried out for the three phase (gas-liquid-solid) flow. Moreover, **YONG et al. (2001) [8]** have investigated characteristics of gas-liquid-solid flow behavior in riser with three phase circulating fluidized bed. By adopting the chaos method to analyze the local gas holdup, solid holdup distribution and pressure fluctuations. **Mohan et al. (2003) [5]** have studied the dynamics of gas-liquid/gas-liquid-solid flows in cylindrical bubble columns using experiments and CFD simulations. The low frequency oscillations corresponding to the local recirculatory flow were characterized using wall pressure fluctuation measurements. Eulerian-Eulerian two-/three phase simulations were carried out with a focus on characterizing the dynamic properties of gas-liquid/gas liquid- solid flows. The effects of superficial gas velocity, H/D ratio and solid loading on the dynamic and time averaged flow behavior were studied experimentally and computationally. **Bello et al. (2005) [1]** have measured the sand holdup in such oil-gas-sand multiphase production and pipeline transportation systems. The local sand holdup measured under conditions analogous to the horizontal oil-gas-sand three-phase slug flow in pipelines. The results revealed the influence of operating conditions such as gas, liquid velocities and sand particle loading on the distribution of the local sand particle holdup in the horizontal air-water-sand multiphase slug flow pipe. **Niels et al. (2007) [7]** have presented a numerical simulation of gas-liquid-solid flows using a combined Volume Of Fluid (VOF) and Discrete Particle (DP) approach applied for dispersed gas bubbles and solid particles respectively present in the continuous liquid phase. **Wang and Yu (2008) [3]** have introduced a numerical study of the gas–liquid–solid flow in hydro cyclones with different shaped vortex finder. In the mathematical model, the turbulent flow of gas and liquid was modeled using the Reynolds Stress Model, and the interface between the liquid and air core was modeled using the Volume of Fluid multiphase model. The results used in the simulation of particle flow described by the stochastic Lagrangian model. The flow features were examined in terms of flow field, pressure drop, split ratio reported to the underflow, particle trajectories and separation efficiency**. Zhihong Li et al. (2011) [4]** have developed an Euler-Euler model to study the dynamics flow of three phase flow (gas-liquid-solid) through a channel. Granular kinetic theory was applied to deal with the particle phase. By study the effects of different inlet velocities and inclined angles of the channel. **Tang et al. (2013) [6]** have studied mixing behaviors by simulated the three-dimensional (3-D) gas-liquid–solid flow in micro channels by coupled volume of fluid and discrete phase method. In this paper, the experimental study for three phase (liquid- gas - solid particles) flow in horizontal pipe and pressure fluctuation along the horizontal pipe has investigated.

II. THE EXPERIMENTAL APPARATUS AND PROCEDURE

The experimental rig has built to measure pressure gradient along the horizontal pipe for three phase flow namely liquid, gas and solid particle as shown in figure (1). The experimental rig has designed with horizontal pipe length and inner diameter are (4 m) and (3.175 cm), respectively. The horizontal pipe includes transparent test section (glass pipe) with length (1m).The experimental equipments include the following:

1. Main water tank with capacity (1 m^3).
2. Air compressor. It has a specification capacity of (0.5 m3) and maximum pressure of (16 bars)
3. Solid particles tank.
4. Flow meter has used to control the water flow rate with range (5-40 l/min).
5. Air flow meter has used to control the air flow rate with range (350-3500 l/hr).

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6. Solid particle regulator has used to control the solid particle.
7. Water pump with specification quantity discharge (0.08 m^3/min) and head (8m).
8. Valves and piping system (3.175 cm)
9. Solid particle filter.
10. Pressure transducer sensors and data acquisition which are used to measure the pressure across the horizontal pipe with range of (0-1) bar with accuracy (0.1…..) . The data acquisition has connected to personal computer by using a suitable program.
11. A Sony digital video recorder of DCR-SR68E model with capacity 80 GB with lens of Carl Zeiss Vario-Tessar of 60 x optical, 2000 x digital. It has used to visualize the flow structure (pattern). The visualized data are analyzed by using a AVS video convertor software version 8.1. A typical sequence snapshots recorded by the camera using a recording rate of 30 f/s.

Experimental were carried out to show the effect of different operation conditions on pressure profile for horizontal pipe. Operation conditions involve the flow discharge of liquid, gas and loading ratio of solid particle. The selected experimental values are presented in table (1).

Flow discharge of liquid(L/min)	**Flow discharge of air(L/min)**	**loading ratio solid particle(kg/sec)**
25	8.333333	0.01
30	16.66667	0.02
35	25	0.03

Table (1) the values of operation conditions used in experimental.

THE EXPERIMENTAL PROCEDURES ARE:

1. Turn on the water pump with initial value of water discharge (25 L/min).
2. Supply the air from the air compressor with initial value of air discharge (18.3333 L/min).
3. 3-Open the regulator valve for the solid particle with initial value of solid particle (0.01 kg/sec) .
4. Record the pressure through the horizontal pipe and photograph the motion of the three-phase flow by the digital camera.
5. Repeat the above steps by changing the second and third value for solid particle at constant value for water and air and record the pressure .
6. Repeat the above steps by changing the air discharge at constant water discharge for different value of solid particle.
7. Repeat the above steps for another value of water discharge.
8. Measure the weight of solid particle which is leaving the pipe in order to determine the mass flow rate of the solid particle and the loading ratio of the three phases.

III. RESULTS AND DISCUSSION

Figures (2) to (4) show that the effects of loading ratio (L_R) on pressure magnitude distribution along the horizontal pipe for different values of water discharge and at different air discharge. It can be observed that the increase of loading ratio (L_R) cause increase the pressure magnitude for different magnitude of water discharge and different air discharge. However, the pressure profiles approximately remain constant which is decrease with increase the distance (x) of horizontal pipe. **Figure (5)** shows the effects of air discharge on pressure profile distribution along the horizontal pipe for water discharge (Q_{water}=35 L/min) with different loading ratio. It can be noticed that the increase of air discharge causes increase the pressure magnitude for different values of loading ratio at constant value of water discharge. **Figures (6)** to **(8)** show the effect of water discharge on pressure profile distribution along the horizontal pipe for different values of air discharge and at different loading ratio. It can be seen that the increase of water discharge cause increase the pressure magnitude for different values of air discharge and different loading ratio. **Figure (9)** show the pressure sensor reading with time. We note that the pressure reading fluctuated with time due to the multiphase flow (gas, liquid and solid). So, the pressure reading has calculated by taking mean value of pressure sensor reading during (1 min.) **Figures (10)** and **(11)** show the visual image of three phase flow behavior in horizontal pipe with water discharge (Q_{water}=25, 30, 35, L/min) respectively and air discharges (Qa = 8.34, 16.67 and 25 L/min) for the three loading ratio (L_R = (a) 0.1, (b) 0.2, (c) 0.3 kg/sec). These images describe the flow behavior which seems to be slug or plug region when the discharge is low. This is due to the low velocity of water at low water discharge. Also, when increase the air discharge the size and of bubbles increases and especially at high air discharge.

IV. CONCLUSIONS

The experimental investigation of the water discharge, air discharge and loading ratio for solid particle effects on pressure distribution of three phase flow in horizontal pipe and the flow behavior has been done. It can be concluded that the:

1. The pressure magnitude increase with increase of loading ratio.
2. The pressure magnitude increase with increasing of water discharge.
3. The pressure magnitude increase with increasing of air discharge.

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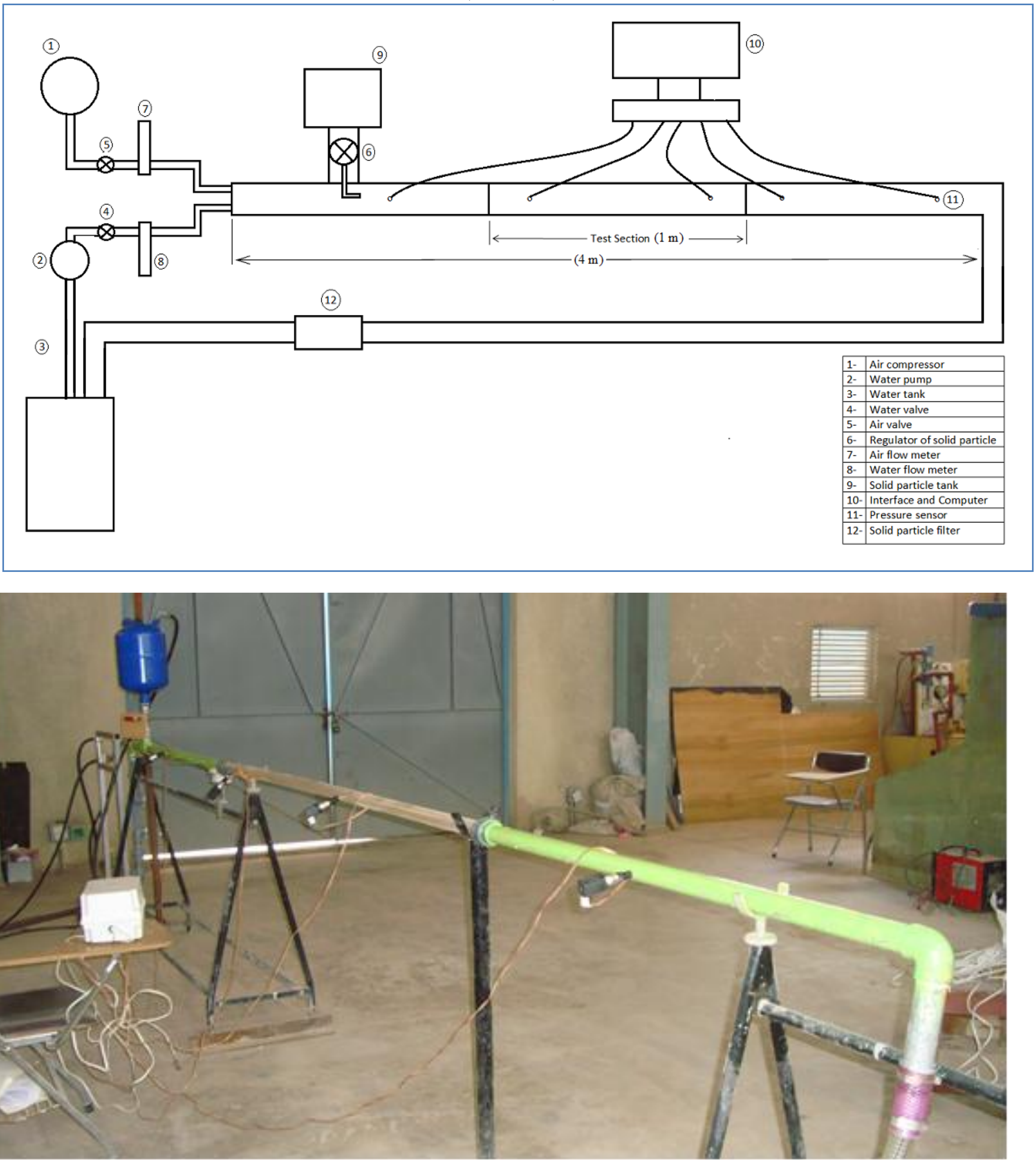

Fig (1) The Experimental Rig

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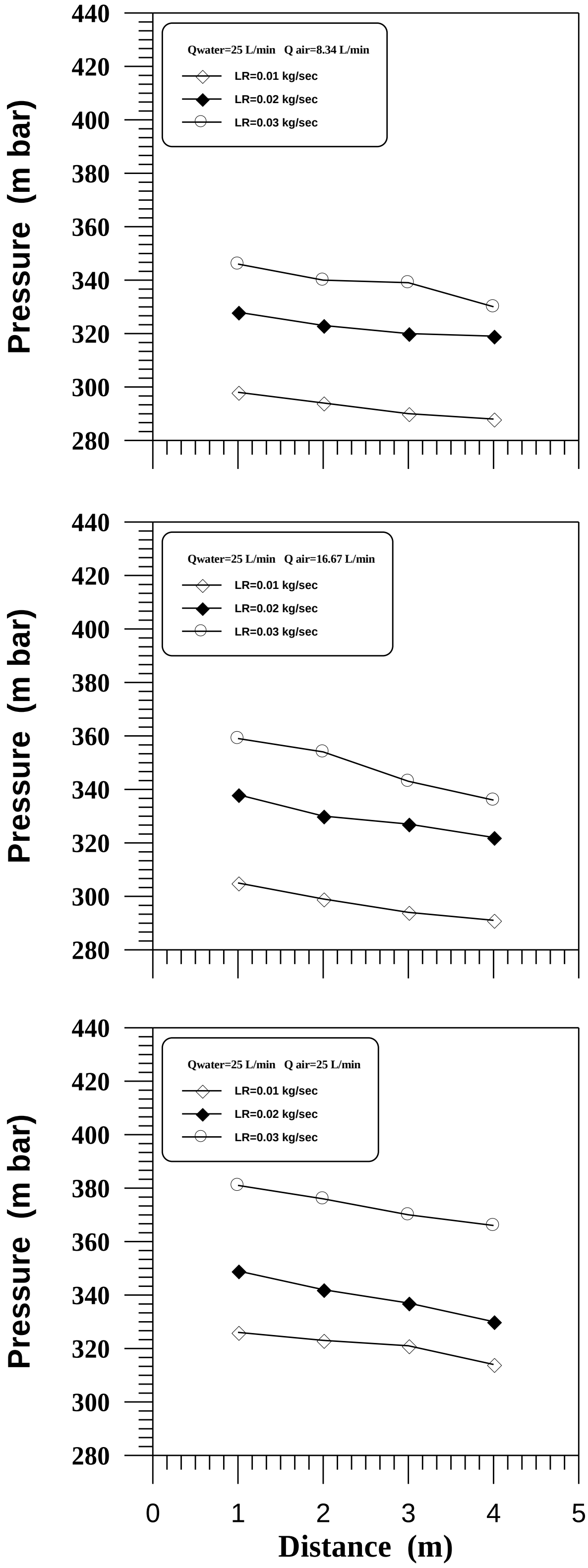

Fig (2): Effect Of Loading Ratio On Pressure Profile At (Q_{water}=25 L/min) For Different Air Discharge

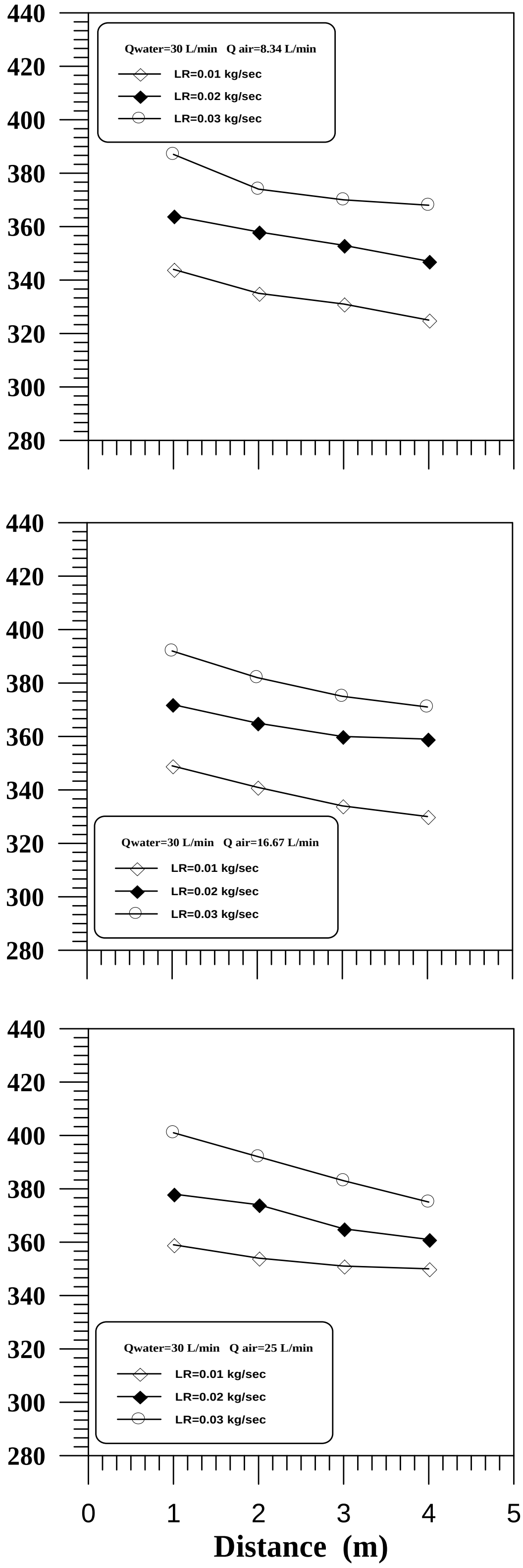

Fig (3): Effect Of Loading Ratio On Pressure Profile At (Q_{water}=30 L/min) For Different Air Discharge

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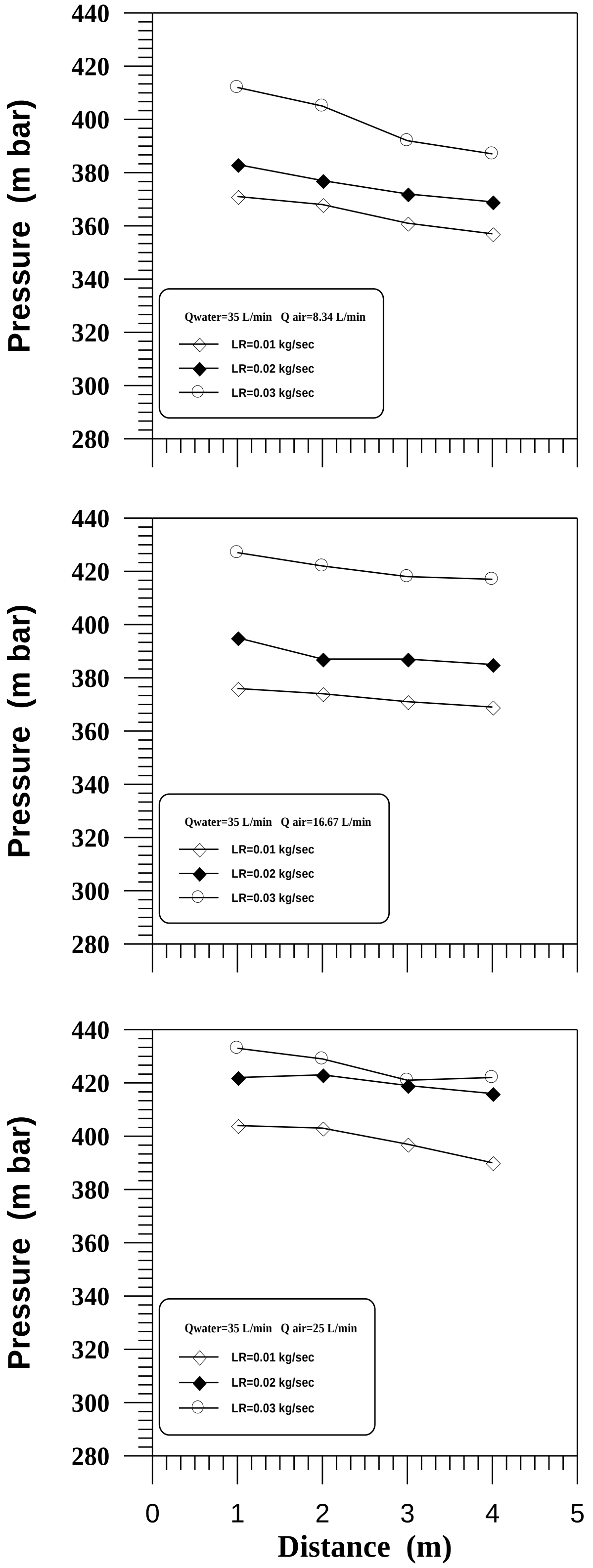
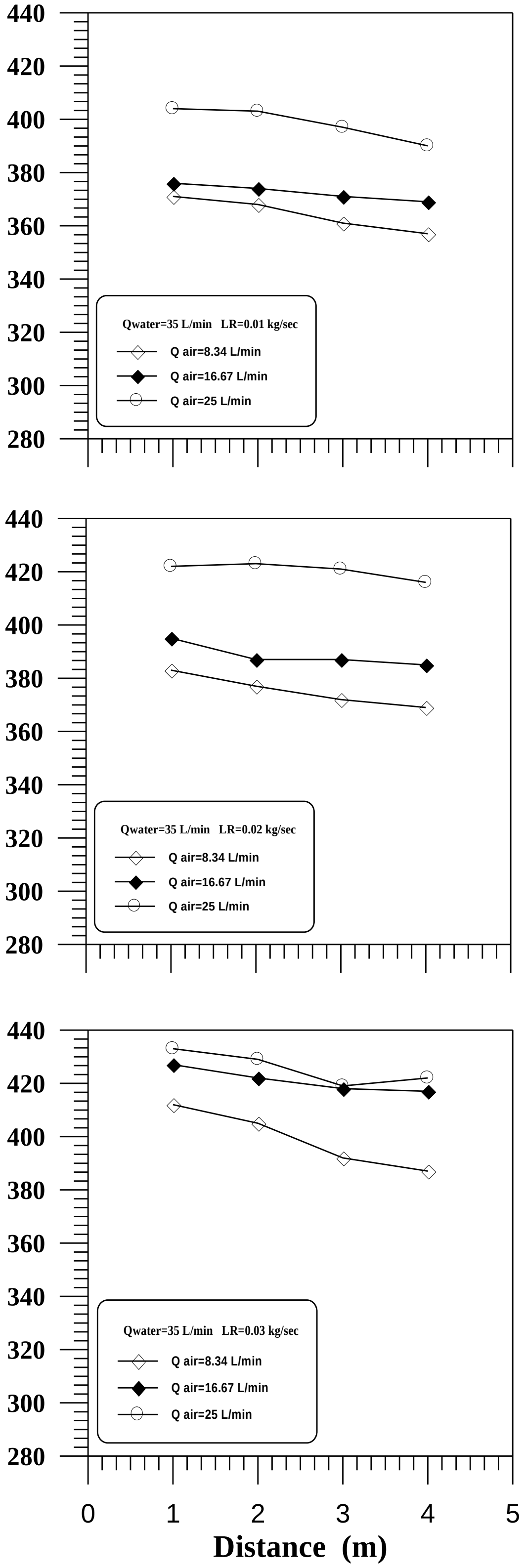


Fig (4): Effect of Loading Ratio on Pressure Profile at (Q_{water}=35 L/min) For Different Air Discharge



Fi (5): Effect of Air Discharge on Pressure Profile at (Q_{water}=35 L/min) For Different Loading Ratio

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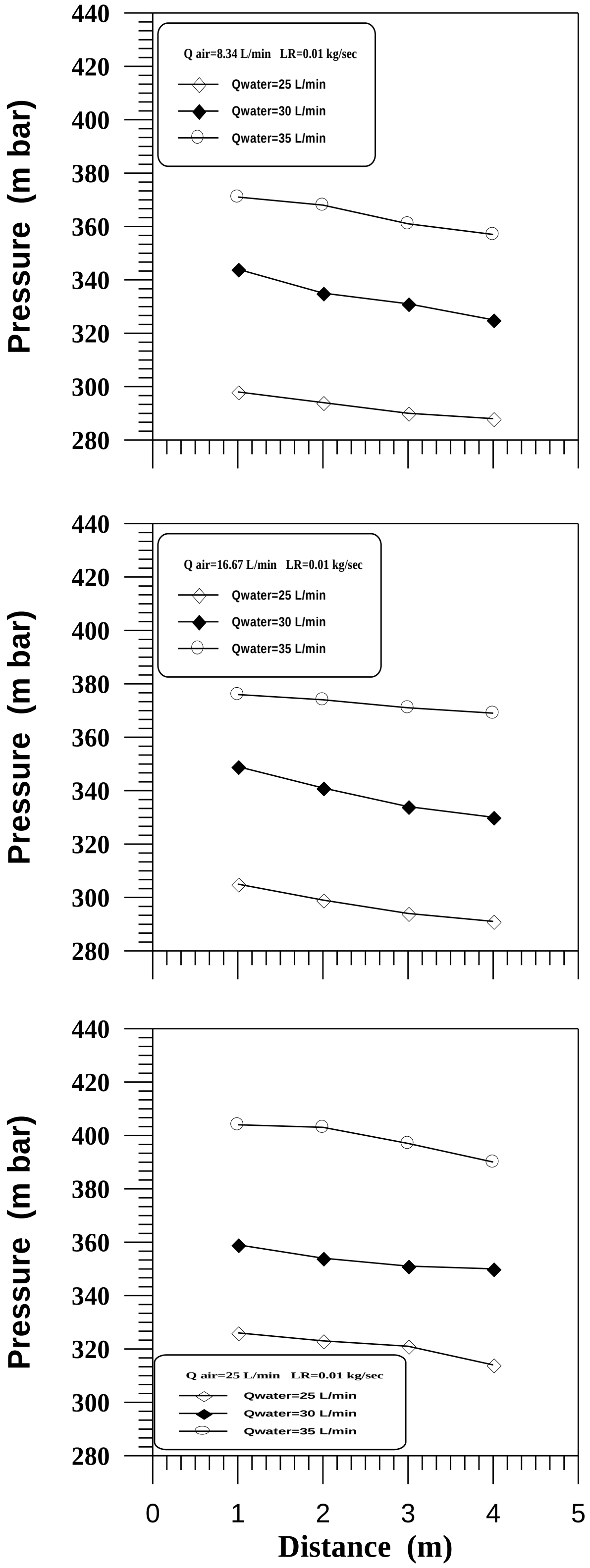

Fig (6): Effect Of water discharge On Pressure Profile at (L_R=0.01 L/min) For Different Air Discharge

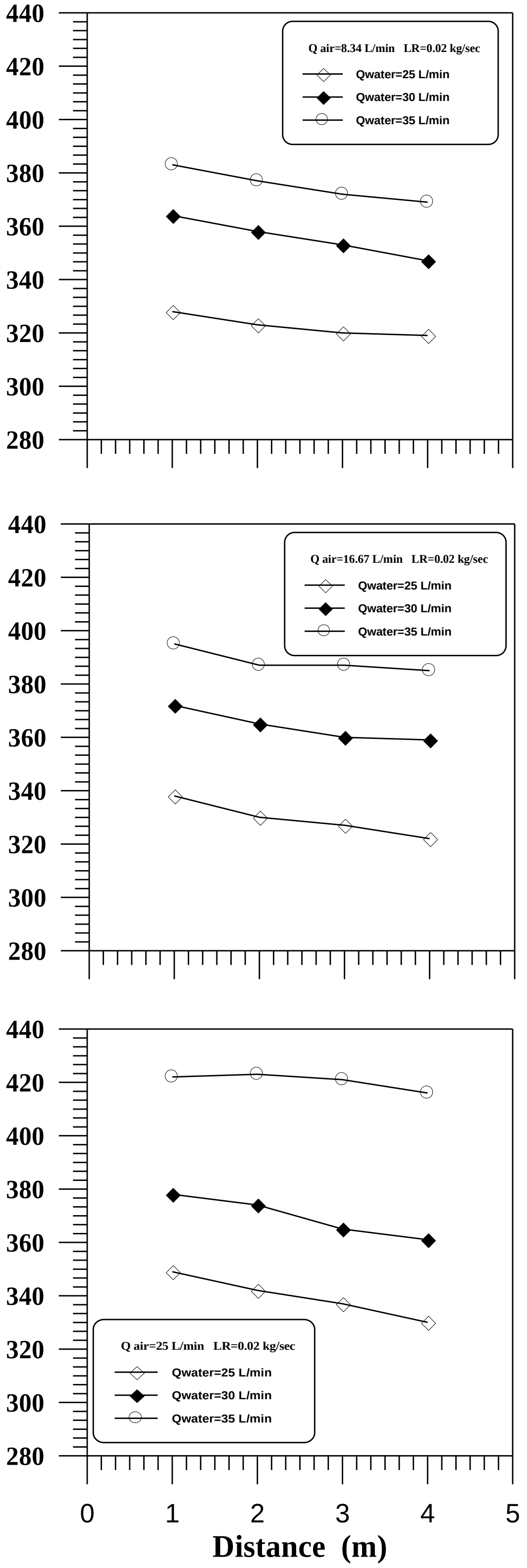

Fig (7): Effect Of water discharge On Pressure Profile at (L_R=0.02 L/min) For Different Air Discharge

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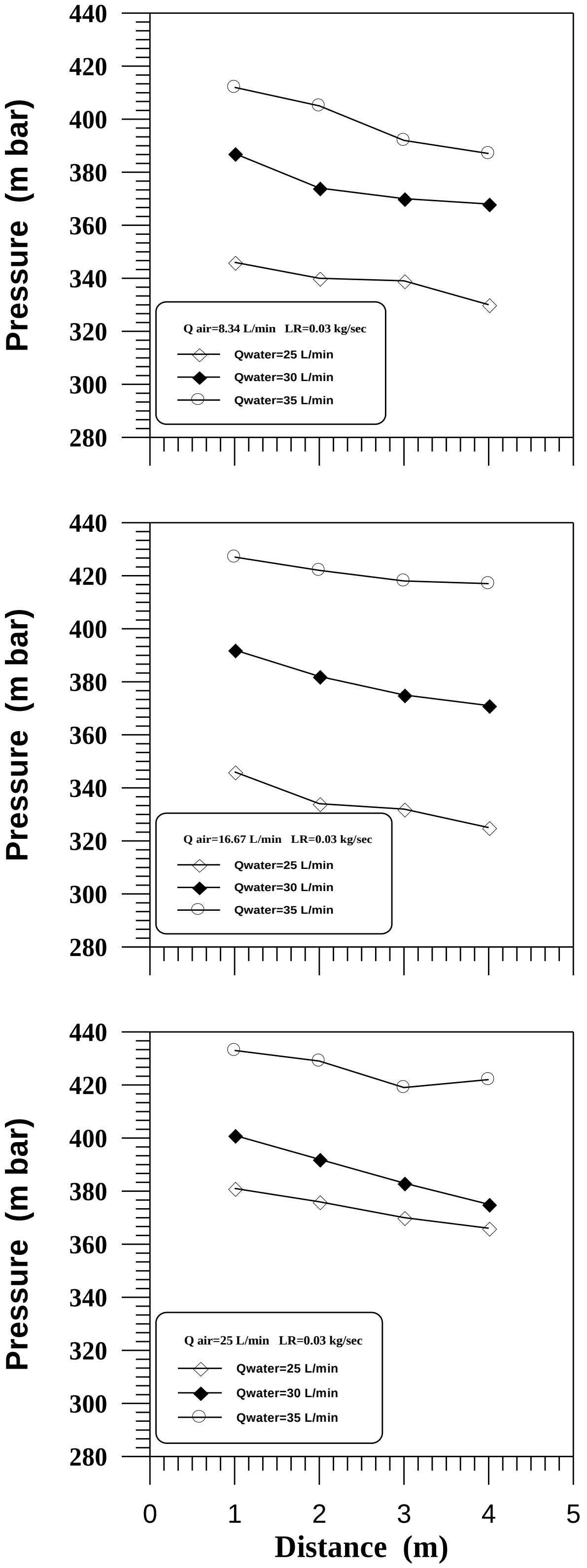

Fig (8): Effect Of water discharge On Pressure Profile at (L_R=0.03 L/min) For Different Air Discharge

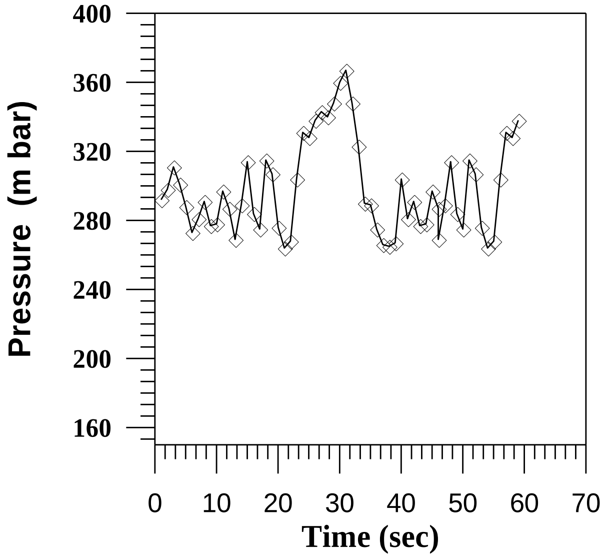

Fig (9) Effect of Time On Pressure Profile

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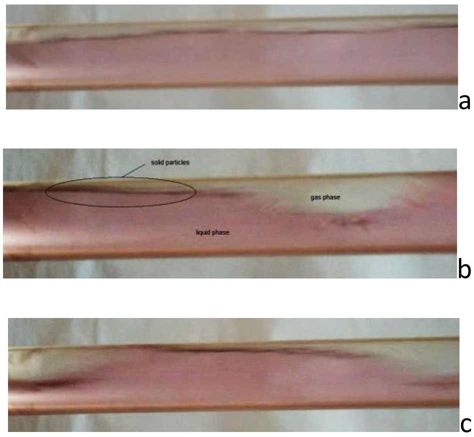
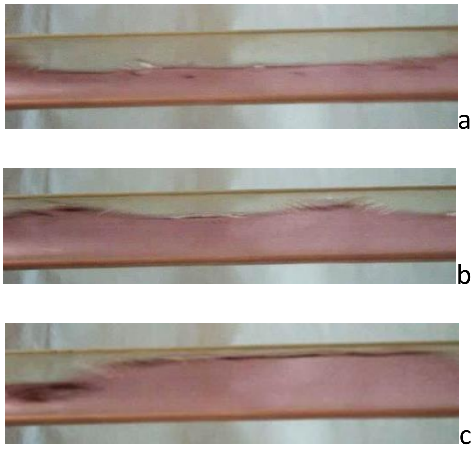
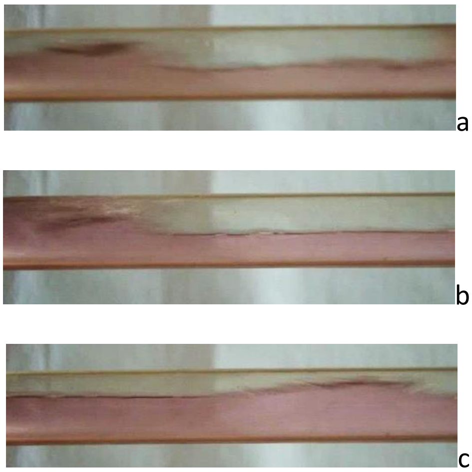


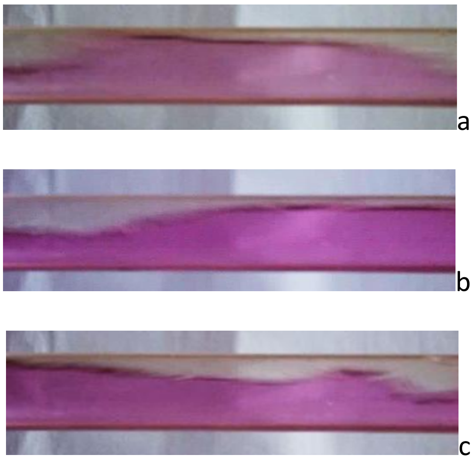
Q_{water} =25 L/min Q_{air} =8.34 L/min



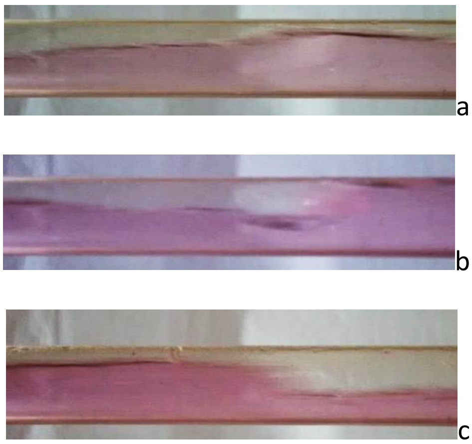
Q_{water} =25 L/min Q_{air} =16.67 L/min



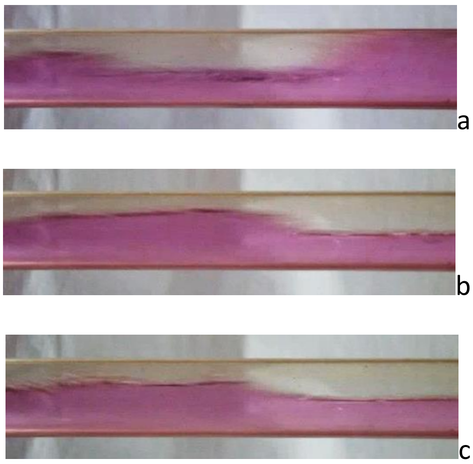
Q_{water} =25 L/min Q_{air} =25 L/min



Q_{water} =30 L/min Q_{air} =8.34 L/min



Q_{water}=30 L/min Q_{air}=16.67 L/min



Q_{water}=30 L/min Q_{air}=25 L/min

Fig (10). Photographs for the three phase flow behavior for different Q_{water} , Q_{air} and L_R=0.01, 0.02 and 0.03 kg/sec respectively.

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a

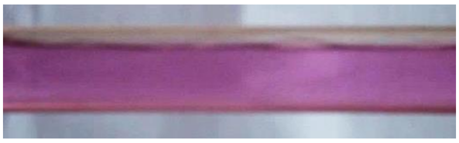
b

c

Q_{water}=35 L/min Q_{air}=8.34 L/min

a

b



c

Q_{water}=35 L/min Q_{air}=16.67 L/min

a

b

c

Q_{water}=35 L/min Q_{air}=25 L/min

Fig (11). Photographs for the three phase flow behavior for different Q_{water} , Q_{air} and L_R=0.01, 0.02 and 0.03 kg/sec respectively.