

Study of Various Flow Pattern and Pressure Drop for Oil-Water Flow in Horizontal Pipe

Samir V.Wankhede

Assistant Professor, Department of Chemical Engineering, JDIET College, Yavatmal, Maharashtra, India¹

ABSTRACT: Flow pattern for water-oil flow in horizontal (inner diameter of 0.6 cm) glass pipe was used. Experiment was based on (1) Study of various flow patterns at different superficial velocity of (water and oil were: 0.28 to 1.467 m/s and 0.24 to 1.64 m/s) water-oil immiscible flow using visualization technique. (2) Pressure drop and hold up measurement using manometer. The analysis reveals that homogeneous model suitable for dispersion flow were as bubbly flow pattern is observed better by drift flux model. In present study stagnant film model and moving film model were used by taking account of velocity of fluid against pressure drop. The stagnant film model was adequate to accurately predict the liquid-liquid slug flow pressure drop having relative error was 3.4 %. Stagnant film model was in good agreement with experimental data with a mean relative error of less than 11%. The purpose of this thesis is to study the behavior of the simultaneous flow of oil and water in horizontal pipes which is common in a diverse range of process industries and particularly in the petroleum industry

KEYWORDS: Flow, Holdup Liquid-Liquid Phase, Pressure Drop, horizontal pipe, Liquid-liquid slug flow Pressure drop

I. INTRODUCTION

Oil-water flow have many applications in coal processing, refrigeration, fluidized based reactor, liquid sprays, separation of contaminant from a mixture and pumping of slurries, flashing liquid, energy conservation, food and paper manufacturing, and pharmaceutical industries etc. Although in many industrial processes multi-phase flow occurs, in transporting multi-phase fluids through pipelines and petroleum wells are major applications. Again in the process industry, nuclear industry, and many other multi-phase flow plays a vital role. Now a days, oil extraction by drilling of horizontal or nearly horizontal wells is often accompanied with a high water throughput, due to the presence of water in old wells or injection of water into the wells for a better oil exploration. The influence of the water phase with respect to the pressure drop is of particular importance for oil fields operating at high water cuts and low wellhead pressures. Therefore, optimization of pipeline operations for transport of these fluids requires the knowledge of the pressure drop and in situ distribution of the liquids.

In the pipe simultaneous flow of oil and water, different shapes and spatial distributions of their deformable interfaces can appear which are commonly called flow regimes or flow patterns. An immense deal of efforts has gone into investigation and classification of flow regimes occurring under various flow conditions and the usual outcome is to express results in terms of "flow pattern map". Since 1990s, due to the development of advanced instrumentation and techniques in multiphase flow measurements, different flow pattern parameters have been measured more accurately and flow patterns of oil-water flow have been analyzed objectively [1, 2]. For two-phase oil-water pipe flow the pressure drop behavior with respect to oil-water ratio has been reported. Charles et al [3] have investigated oil-water flow in horizontal pipe and the results are applicable where oil and water have equal density. For oils with medium and high viscosity, pressure drop in stratified flow decreases monotonically with increasing water fraction from single-phase oil to single-phase water [2]. For high viscosity and low density difference, an annular water film is formed on the walls and the pressure drop becomes very low as reported in Charles et al [3]. For oil having viscosities in the order of water (or slightly above) the pressure drop in stratified flow is approximately constant and changes only slightly with oil fraction. It mainly depends upon the viscosities and densities of oils.

Most of the work done in horizontal pipes has been in case of gas-liquid flow, while relatively few studies are focusing on the hydrodynamics of liquid-liquid systems. [4]. In comparison to liquid-liquid flow, there is a need of enough information on the flow and phenomenon of liquid-liquid flows. On the other hand, the water proportion in crude oil is increasing day by day because of reservoir aging as reported in Wenhong et al [5]. As a result, the flow of oil-water mixtures is becoming a growing area of research Jana et al [6]. The mixtures of two immiscible liquids are normally included in the design of a variety of practical equipment. For example, in transportation of viscous liquid if small

amount of water is added to the oil that may reduce the viscosity and pressure gradient as compare to single phase oil flow Rouhani and Shoal [7].

The flow pattern depends on a many parameters, like input phase fraction, the individual fluid velocities, the viscosity, interfacial tension and density of phases, the pipe shape and dimension. Wang [8]. Depending on the total flow rate and the volumetric flow ratio, several liquid–liquid flow patterns are achievable in pipes such as stratified flow with either smooth or wavy interface; slug flow, elongated or spherical bubble of one liquid in the other; a dispersion of relatively fine drops of one liquid in the other; annular flow where one of the liquids forms the core and the other liquid flows in the annulus. In many cases, however, the flow pattern consists of a combination of these basic prototypes. When water is the continuous phase, oil viscosity seems to have a minor effect on the flow patterns. However, the oil viscosity affects the phase inversion point for the two dispersions i.e., oil in water dispersion ($D_{w/o}$) and water in oil dispersion ($D_{o/w}$). Due to the relatively low density difference between the two fluids, the role of gravity in liquid–liquid systems diminishes. Therefore wall-wetting properties of the liquid and surface tension forces become important and may have a significant effect on the flow pattern Al-Moosawy et al [9]. Observation of flow patterns and spatial distribution of the two-phase flow included, in the studies of liquid-liquid flow within the pipe. In the reactor design the pressure drop is a valuable factor, as it offered essential information regarding the required pump capacity, energy consumption as well as the materials needed for the reactor construction. The pressure drop is not only a function of the mass flow rates and transport properties of the two liquids, but also depends on the flow patterns and the in situ proportion of the two phases. Unfortunately, the complete data for flow pattern, pressure drop and holdup are not available for oil-water flow through small diameter horizontal pipe. In liquid -liquid flow, the interface between the two phases can exist in a wide variety of forms, depending on the flow rate, fluid properties of the phases and the geometry of the system. Flow patterns are used to describe this distribution. The flow patterns are one of the important features of two-phase flows. The hydrodynamics of the flow, as well as the flow mechanisms, change significantly from one flow pattern to another. In order to estimate accurately the pressure drop and holdup, it is necessary to know the actual flow pattern under the specific flow conditions. From the literature survey it was observed that most of the researchers have focused their attention on gas-liquid flows. On the other hand, few works have been published on liquid-liquid two-phase flow. In most of them, the researchers have used water and a highly viscous oil as the test fluids in a horizontal or nearly horizontal test section to study the reduction in pressure during core annular flow [6]. Mukherjee et al [10] determined pressure drop and water holdup for oil-water flow in 0.038m diameter pipe with varying inclination angles from $\pm 30^\circ$ to $\pm 90^\circ$ from horizontal. They reported pressure losses higher than the calculated values and which reached maximum at the phase inversion point. Angeli and Hewitt [11] investigated flow structure in co-current flow using 1.6 m Pa.s viscosity oil and water. They used two pipes with different materials of 0.0254 m stainless steel and acrylic resin pipe. They investigate that different flow patterns were observed over a wide range of conditions, series from stratified to fully mix but they did not find any annular flow. Yao and Gong [12] performed experiments at viscosity of 614.7mPa.s having density 968.82 kg/m³ on heavy oil/water flow. The flow patterns were divided into 4 case (1) water dominated, (2) oil dominated, (3) segregated flow region and (4) intermittent flow region. Rodriguez and Oliemans [13] investigated flow patterns, phase holdups and pressure gradients have been measured for horizontal and inclined (-5° , -2° , -1.5° , 1° , 2° and 5°) oil/water flow in an 8.28 cm diameter steel pipe using mineral oil and brine as fluids. They reported that, For downward inclined flow a stable wavy structure was observed. For upward inclined flow regions with high water recirculation were detected. The stratified smooth flow pattern disappears with inclination and is replaced by a stratified wavy flow pattern. Lovic and Angeli [14] carried out their experiments with oil-water flow in a horizontal pipe and noted that the addition of water to oil resulted in pressure gradients less than that of single phase oil flow. The authors also reported that the standard two-fluid model was unable to predict the pressure gradient and holdup during dual continuous flow. Chakrabarti et al [15] investigated the flow of kerosene-water mixture through a 0.025m diameter horizontal pipe. The velocity was varied from 0.03 to 2 m/s. They found that an increase in the measured pressure drop as a result of an increase in the superficial velocity. They attributed this to the fact that when the water flow rate is increased, a larger fraction of the pipe wall is covered by a rough interface formed between the water and oil. The presence of a rough surface leads to an increased friction factor and pressure gradient. Sotgia et al [16] conducted experiments on flow of water and mineral oil in horizontal pipe of diameters ranging from 0.021 to 0.040 m. The oil used had a viscosity of 678 mPa.s and density of 886.3 kg/m³ at 20°C. They found that the pressure drop reduction is a function of the water volume fraction. Therefore, present study aims to investigate flow pattern visually and using high speed camera, also study holdup and pressure drop experimentally as well as theoretically for different flow patterns.



II. EXPERIMENTAL SET UP AND PROCEDURE

The representative diagram of the experimental setup designed and fabricated for investigating horizontal flow pattern and pressure drop of kerosene-water flow is shown in the fig. 1. It consist of a horizontal test section, a water tank, a kerosene tank, a separator tank, and two centrifugal pumps of 55 W and two rotameter of capacity of $7 \times 10^{-5} \text{ m}^3/\text{s}$. The test section consisted of a horizontal transparent glass tube of inner diameter of $6 \times 10^{-3} \text{ m}$, outer diameter of $12 \times 10^{-3} \text{ m}$ and a length of 1.42 m. The transparent glass tube gives better visual observation of the flow phenomenon as well as helps in photography. To ensure fully developed flow an entry length of 0.06 m was provided having a length to diameter ratio of 100. To avoid any disturbance in the test section an exit length of 0.03 m was also provided. In the test section glass tube of 0.92 m was used for photography. For better visualization of flow pattern, test fluid, water and blue kerosene were used in the experiment. These fluids were pumped by two centrifugal pumps (P1 and P2) from their respective storage tanks. The flow rates were measured by the rotameter. The two liquids are brought in contact with each other by a T-arrangement at the entry where oil enter from vertical and water in horizontal direction. After the test section, kerosene and water mixture enter into the separator tank and form two separate layers. Then two layers are separated manually.

Table 1. The physical properties of water and kerosene (at 298 K and at atmospheric pressure)

Material	Density (kg/m^3)	Viscosity ($\text{N s}/\text{m}^2$)	Surface tension (N/m)
Kerosene	793	0.0014	0.014
Water	1000	0.00085	0.033
Water mixed with potassium dichromate	1592	0.001	0.065

Interfacial tension for water and kerosene is 0.0315 N/m.

The superficial velocity of both water and kerosene were varied by changing flow rate between 0.242 m/s and 1.64 m/s. In the experiment water velocity was kept constant and kerosene velocity was changed from low to high. Repetitive reading was obtained by changing water velocity in increasing order. In next case all the measurements were obtained in reverse way i.e. keeping kerosene velocity constant and increasing water superficial velocity continuously in increasing order. For all combinations of flow rates, experimental pressure drop was measured by differential pressure transducer after calibration. During experimentation precaution has been taken so that no kerosene enters into the tubes connecting test pipe and the differential pressure transducer.

Further, the water holdup (H_w) has been measured by using two quick closing valves and the same is calculated by the following formula,

$$H_w = \frac{V_w}{V_w + V_o} \tag{2}$$

Where V_w and V_o are the measured volume of water and kerosene, respectively, after taking out the oil-water mixture out of the test section. The oil holdup (H_o) is calculated by using the equation given below.

$$H_o = 1 - H_w \tag{3}$$

The inlet volume fraction (β) of water is calculated from the following equation.

$$\beta = \frac{Q_w}{Q_w + Q_o} \tag{4}$$

Where Q_w and Q_o denote the volumetric flow rates of water and oil respectively those are measured by calibrated rotameter.

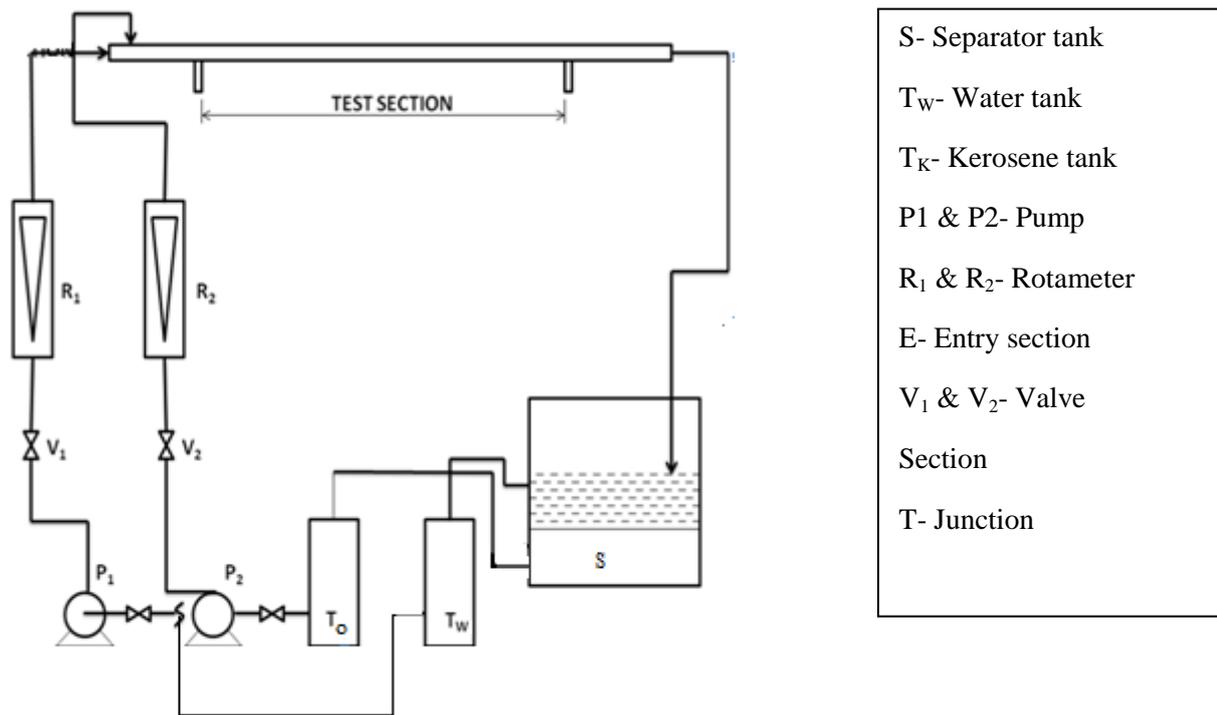


Fig. 1. Schematic diagram of experimental setup.

III. RESULTS AND DISCUSSIONS

In the present study, attempt has first been made to identify flow patterns by using a high speed camera of AOS Imaging Studio V2.5.3.3 with 1000fps. Then pressure drop has been measured in different flow patterns at different flow rates of oil and water. The measured experimental pressure drop has next been validated by different theoretical models.

3.1 Identification of flow pattern

To detect different flow patterns first visual observation was made. It was successful at low mixture velocities. As total velocity is increased high speed photographic technique was essential to detect the interfacial configuration who ever high speed photography was also failed to identify the flow pattern in some combination of two fluid velocity in the range of velocity studied one representative image of each flow pattern has been given in table 2.



Table 3.1: Flow pattern observed at different superficial velocity of water and oil flow

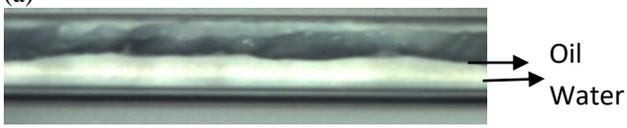
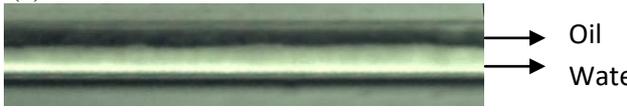
Superficial velocity of water (m/s)	Superficial velocity of oil (m/s)	Flow pattern observed*
0.28	0.242	SM
0.28	0.345	SM
0.28	0.365	SW
0.28	0.456	B
0.28	0.611	B
0.28	0.783	B
0.28	0.931	B
0.28	1.033	B
0.28	1.184	B
0.28	1.312	B
0.28	1.495	B
0.28	1.582	DF
0.28	1.640	DF
1.467	0.242	DF
1.467	0.345	DF
1.467	0.365	DF
1.467	0.456	SF
1.467	0.611	SF
1.467	0.783	SF
1.467	0.931	SF
1.467	1.033	AF
1.467	1.184	AF
1.467	1.312	DF
1.467	1.495	DF
1.467	1.582	DF
1.467	1.640	DF
0.525	0.931	P
0.611	0.931	P
0.69	0.931	P
0.280	0.242	SM
0.356	0.242	SM
0.433	0.242	B
0.525	0.242	B
0.611	0.242	B
0.723	0.242	SF
0.795	0.242	SF
0.888	0.242	SF
1.025	0.242	SF
1.106	0.242	SF
1.230	0.242	SF
1.370	0.242	DF
1.467	0.242	DF
0.280	1.64	B
0.356	1.64	B
0.433	1.64	B
0.525	1.64	SF
0.611	1.64	SF
0.723	1.64	AF
0.795	1.64	AF
0.888	1.64	DF

1.025	1.64	DF
1.106	1.64	DF
1.230	1.64	DF
1.370	1.64	DF
1.467	1.64	DF

3.1.1 Stratified flow

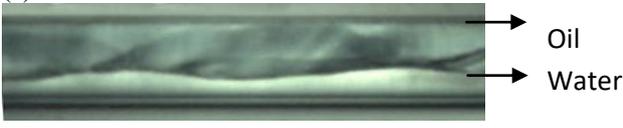
Stratified flow observed at lower mixture velocity in which the lighter liquid i.e., oil flows as a layer on the upper part of the tube and the heavier liquid flows as a separate layer in the bottom part as shown in Table 3.2.

Table. 3.2 Stratified flow.

Superficial velocity of water U_{SW} (m/s)	Superficial velocity of kerosene U_{SO} (m/s)	Image of Stratified flow pattern
0.28	0.24	(a) 
0.35	0.24	(b) 

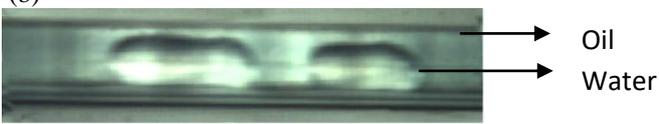
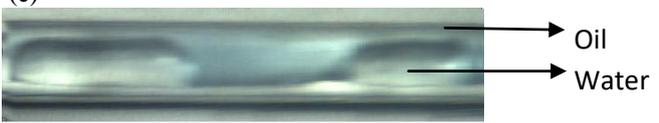
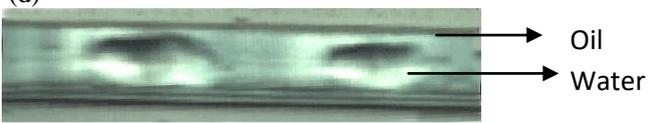
Figures 1 (a and b) indicates, as velocity of fluid increase, it was seen that flow pattern becomes change than previous observed pattern mean it changed from stratified flow to stratified wavy flow pattern. Data reveal that, as mixture velocity increases drop appeared in interfacial region and flow pattern become stratified wavy as shown in table 3.3.

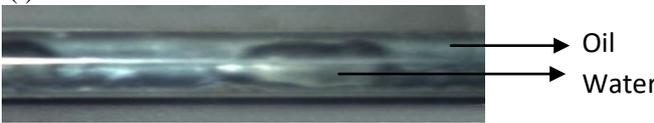
Table. 3.3. Stratified wavy flows.

Superficial velocity of water U_{SW} (m/s)	Superficial velocity of kerosene U_{SO} (m/s)	Image of Stratified wavy flow pattern
0.28	0.36	(a) 

Bubble flow pattern observed as shown in table 3.4.

Table.3.4. Bubbly flow.

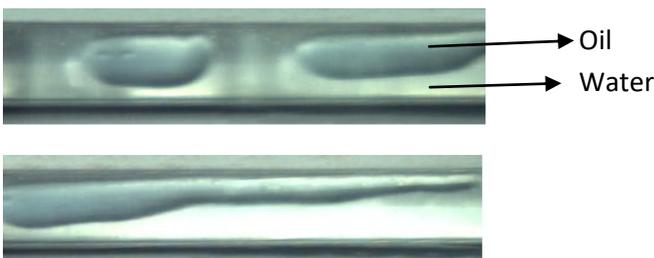
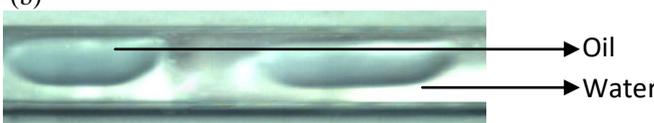
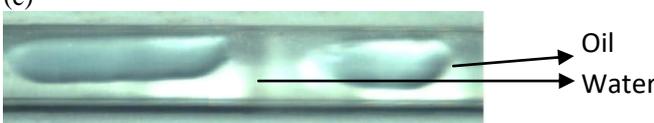
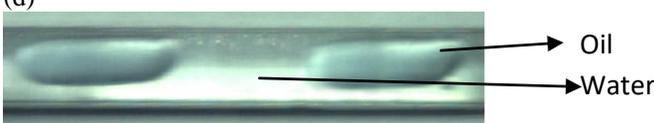
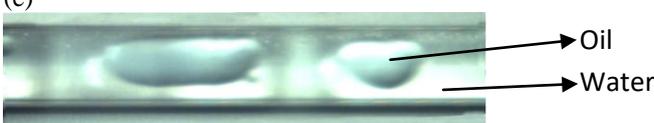
Superficial velocity of water U_{sw} (m/s)	Superficial velocity of kerosene U_{so} (m/s)	Image of Bubbly flow pattern
0.28	0.61	(a) 
0.28	1.03	(b) 
0.28	1.31	(c) 
0.28	1.49	(d) 
0.433	0.24	(e) 
0.52	0.24	(f) 
0.28	1.64	(g) 
0.356	1.64	(h) 

0.43	1.64	(i) 
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From above table effect on bubble was observed with change in velocity of kerosene at constant water flow that, size of bubble would decrease as increase in frequency of number of bubble result in distance between two bubbles was decrease.

Slug flow observed condition high flow rate of water and lower flow rate of kerosene at condition large continuous oil pockets similar to Taylor bubble can observe see in table.3.5. It was observed that as water velocity was increased the bubble length decrease .

Table. 3.5. Slug flow.

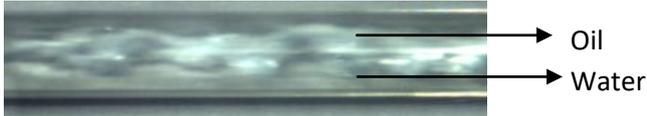
Superficial velocity of water U_{sw} (m/s)	Superficial velocity of kerosene U_{so} (m/s)	Image of slug flow pattern
0.72	0.24	(a) 
0.88	0.24	(b) 
01.025	0.24	(c) 
1.106	0.24	(d) 
1.230	0.24	(e) 

From above table 3.5 It was observed that at constant superficial velocity of oil keeping constant while increasing the superficial velocity of water the size of bubbles decreases it was also observed that with increasing water

velocity at constant oil velocity separation between two consecutive bubble decreases. i.e. frequency of bubble increases.

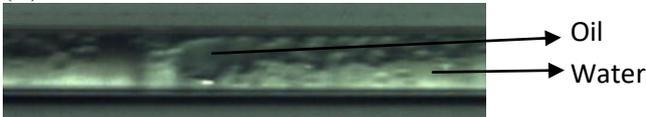
Core annular flow pattern was obtained at higher oil and lower water flow rate water phase was observed to flow through the annular between the tube wall and oil core. Photograph of core annular flow patterns as shown in table 3.6 At different flow rate of oil and water.

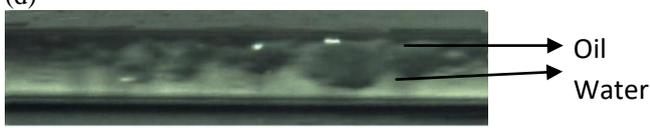
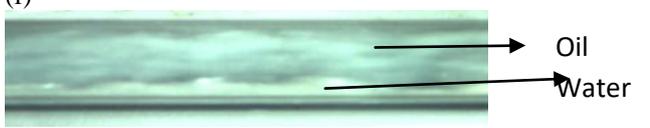
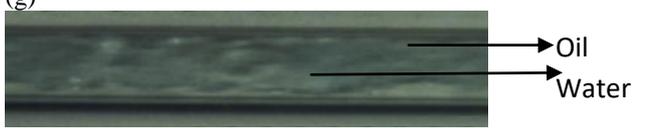
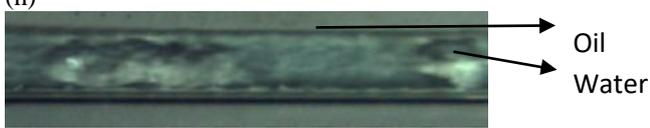
Table. 3.6. Annular flow.

Superficial velocity of water U_{SW} (m/s)	Superficial velocity of kerosene U_{SO} (m/s)	Image of Annular flow pattern
0.72	1.64	(a) 
1.47	1.03	(b) 
1.47	1.18	(c) 

Dispersed flow pattern in which one phase is dispersed into another more or less uniformly and occupied the whole cross section of pipe this flow pattern occur at higher mix velocity as shown in table 3.7

Table. 3.7. Dispersed flow .

Superficial velocity of water U_{SW} (m/s)	Superficial velocity of kerosene U_{SO} (m/s)	Image of Dispersed Flow pattern
0.28	1.64	(a) 
1.47	0.24	(b) 
1.47	0.36	(c) 

1.47	0.611	(d) 
1.47	0.931	(e) 
1.47	1.49	(f) 
1.47	1.64	(g) 
0.88	1.64	(h) 
1.106	1.64	(i) 

From above table it was observed that if water and oil are at their maximum superficial velocity Dispersed flow occupies the whole cross section of pipe. It is also seen that when the superficial velocity is low and superficial velocity is high then dispersed of water in oil was observed and in reverse case dispersed of oil in water observed.

As we know study of flow pattern in very sensitive because as discussed in literature that visualization technique having some drawback like lack of light, lake of picture capturing capacity and due to its high sensitivity there is a chance of human error in term of flow pattern observation. The flow rates of oil and water can be varied individually producing different flow patterns according to variations in mixture velocity different flow pattern are seen, stratified wavy and bubbly, dispersed, slug pattern. The main focus in this work was on bubbly, dispersed and slug flow pattern. As the variation is done in fluid superficial velocity the different flow pattern are observed which are given below table with images which are taken high speed video camera. In the image the variation in flow pattern are observed fluid by this all data we observed the different flow pattern. From above table it was observed that if water and oil are at their maximum superficial velocity Dispersed flow occupies the whole cross section of pipe. It is also seen that when the superficial velocity is low and superficial velocity is high then dispersed of water in oil was observed and in reverse case dispersed of oil in water observed.

As we know study of flow pattern in very sensitive because as discussed in literature that visualization technique having some drawback like lack of light, lake of picture capturing capacity and due to its high sensitivity there is a chance of human error in term of flow pattern observation.

3.2 Flow pattern map

The literature review showed that there is no universal flow pattern map for the horizontal flow of two immiscible liquids. A survey of literature data on flow pattern maps for liquid–liquid systems follow. Wegmann [17] use two

graphic renditions superficial velocities of the two phases mean the superficial velocity of water vs. superficial velocity of oil. The latter way of presenting the data is also used by [13] presented their data in diagrams with axes denoting the superficial velocity of the two liquids. It is not possible to show all the influences in a two dimensional diagram. In the small pipe, dispersed flows show up for higher kerosene velocities. This is due to the degree of turbulence, which is higher in the bigger pipes. The areas where annular flow structures exist are in the small pipe considerably larger than in the 6.0 mm pipe. This is because a smaller pipe diameter discriminates stratified flows and dispersed flows as it is described in literature. The transition from stratified flow to other flow structures varied in lower diameter pipe than higher diameter pipe this may be due to increasing surface forces with decreases in diameter of pipe.

$$Bo = \frac{(\rho_{Water} - \rho_{Paraffin}) \times g \times D_{Pipe}^2}{\sigma} \tag{6}$$

Where,

- B_o= Bond Number
- ρ_{water} = density of water (kg/m³)
- ρ_{paraffin}= density of paraffin (kg/m³)
- σ= interfacial surface tension

Which means, for Bo > 1 gravitational forces are dominant and for Bo < 1 surface tension forces are dominant. In this work, for the 5.6 mm pipe, the Bond number is Bo = 0.891 and for the 7.0mm it is Bo=1.393 from literature. For current work 6.0 mm pipe it is Bo = 2.32. From this observation it say that in small pipe, gravitational forces is stronger than in the bigger pipe. The three main comparisons between reported and present work is shown in table 4.8 interfacial tension is between two phases is lower by factor of 1.82 Secondary viscosity of water to oil is moderate by factor of 1.16 and 0.87 thirdly pipe diameter is larger by factor 4.05, 2.1 and 1.16.

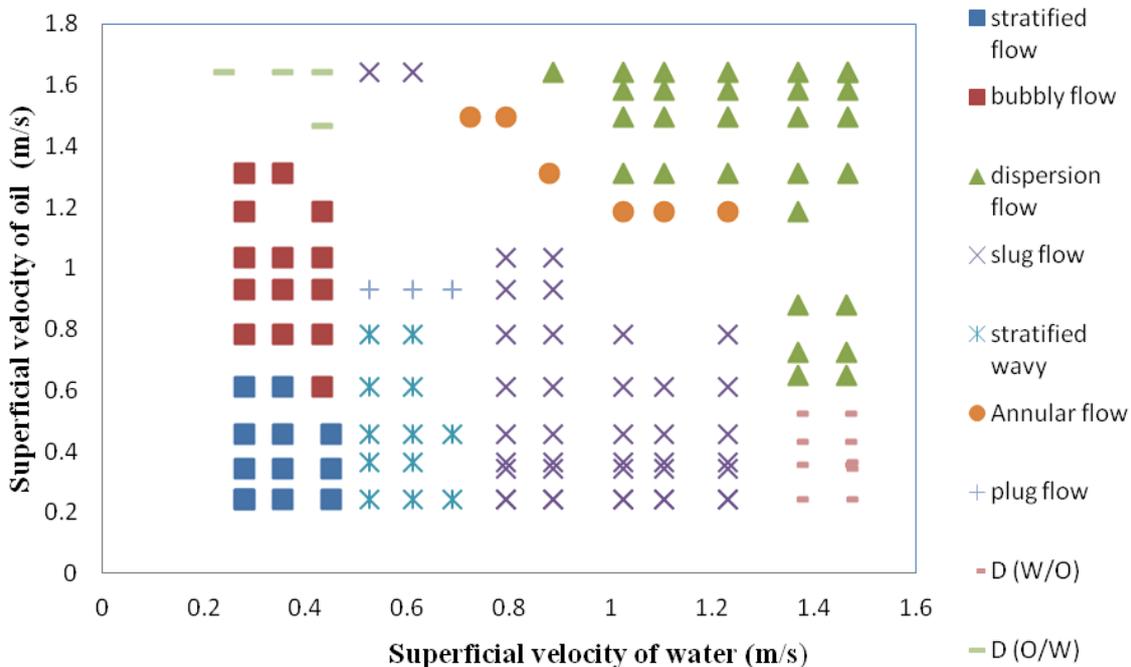


Fig.3.1: Flow pattern map in horizontal pipe

In present study for the investigated pipes with a diameter of 5.6 mm and 7 mm, and 6 mm three major differences to the flow maps observed in larger pipes were found first, stratified flows occur in a much smaller area of flow properties than in bigger pipes. This is due to the interaction of interfacial tension forces and gravitational forces. The smaller pipe diameter is, the easier interfacial tension forces can overcome gravitational forces and the phase with the lower

viscosity can wet the whole circumference of the pipe and plug flow can develop. Second, dispersed flows occur with higher velocities than in bigger pipes. Third, the area where intermittent flows occur grows with decreasing pipe diameter. From this three main important parameter affect the flow pattern density ratio, viscosity ratio and interfacial surface tension.

3.3 Comparison of theoretical and experimental pressure gradient and hold up for different flow pattern

It is obvious that the pressure drop has played a great role in the design and running of oil-water flow system.

3.3.1 Dispersed flow pattern

In this flow homogeneous model is suitable because of value H_w and β are close of for prediction of pressure drop. This model treated the two phase mixture as pseudo fluid with suitable average properties the pressure drop comprising of only frictional component calculated as given.

$$\frac{dp}{dz} = 2f\rho_m \frac{U_m^2}{D} \tag{7}$$

$$U_m = U_{so} + U_{sw}$$

Above equation $\frac{dp}{dz}$, U_{sw} , U_{so} , f , ρ_m , U_m , D , and g show the pressure gradient, superficial water velocity, superficial oil velocity, friction factor, mixture density, mixture velocity, pipe diameter and gravitational acceleration respectively. The acceleration component of pressure drop has been ignored because of the uniform pipe cross-section and no phase change. The gravitational component is also ignored as the flow is through horizontal pipe line. The mixture density ρ_m is calculated from the individual phase density using the following equation.

$$\rho_m = H_w \rho_w + H_o \rho_o \tag{8}$$

RMS deviation is calculated by using
$$= \sqrt{\sum_{i=1}^n \frac{(X_{1i} - \bar{X})^2}{n}} \tag{9}$$

Where,

\bar{X} = arithmetic mean and
 n = number of sample.

Theoretical pressure drop was determined by using following formula:

$$\Delta P = h * g(\rho_m - \rho_w) \tag{10}$$

Where h = difference in height of CCl₄ in U-tube manometer,

ρ_m = density of CCl₄,

ρ_w = density of water,

Friction factor obtained by using following formula

$$f_m = \frac{16}{Re_m} \text{ for } Re_m < 2100 \tag{11}$$

and
$$f_m = \frac{0.079}{Re_m} \text{ for } 2.1 \times 10^3 < Re_m < 10^5 \tag{12}$$

where
$$Re_m = \frac{\rho_m U_m D}{\mu_m}$$

Re_m , U_m , and D are the Reynolds number of the two-phase mixture, mixture velocity and pipe Diameter respectively. from McAdams formula given by,

$$\frac{1}{\mu_m} = \frac{X}{\mu_o} + \frac{1-X}{\mu_w} \tag{13}$$

Where X weight fraction of kerosene, o, m, w denote oil mix and water.

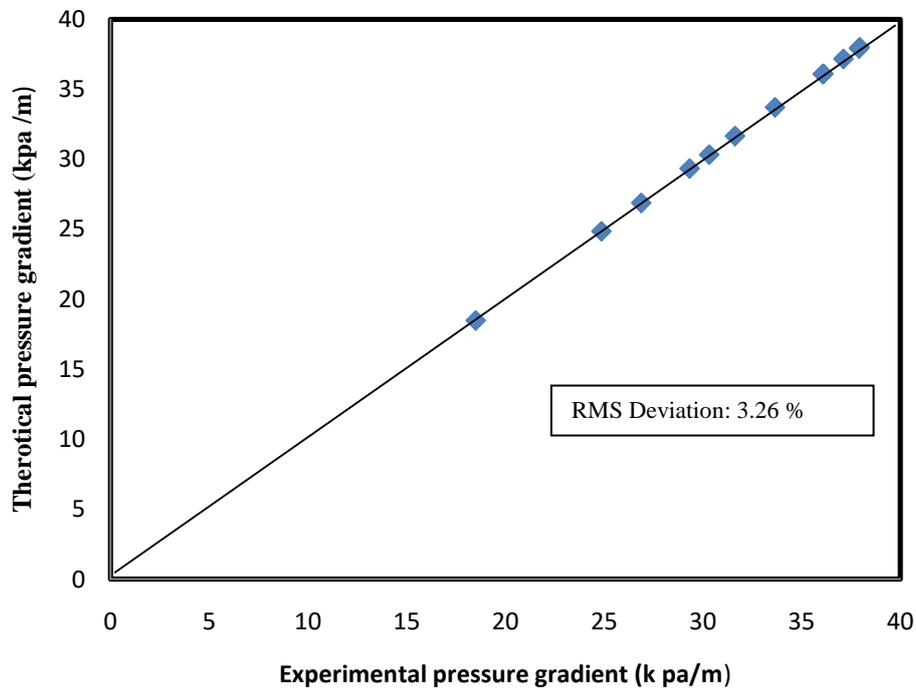


Fig.3: Comparison of experimental pressure gradient with homogeneous model for dispersed flow

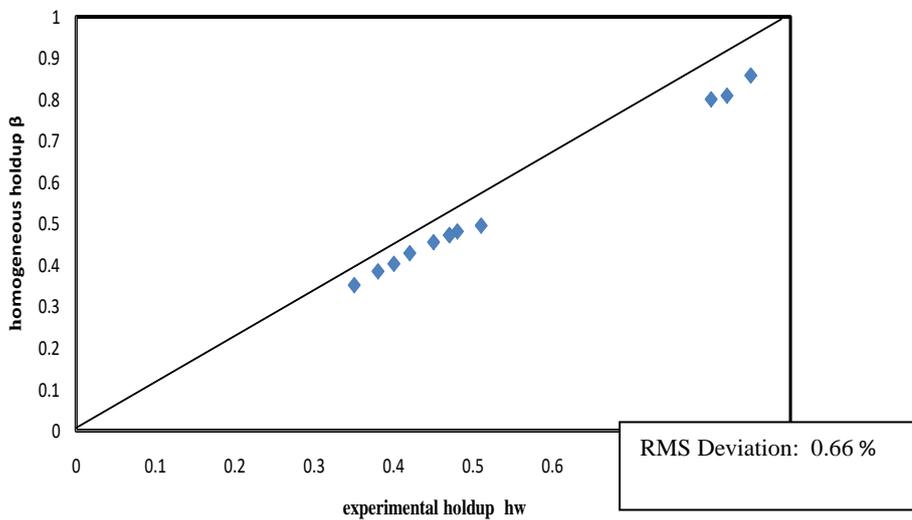


Fig. 4: Comparison of experimental holdup with homogeneous model for dispersed flow.

From figures 3 and 4. It can be observed that the values calculated for the pressure gradient are almost equal to the experimental values calculated with a RMS deviation of 3.26%. The values for the experimental holdup and

homogenous holdup are almost same with an RMS deviation of 0.66% from this we can say that the homogenous flow model is better for calculating the dispersed flow patterns.

3.3.2 Bubbly flow

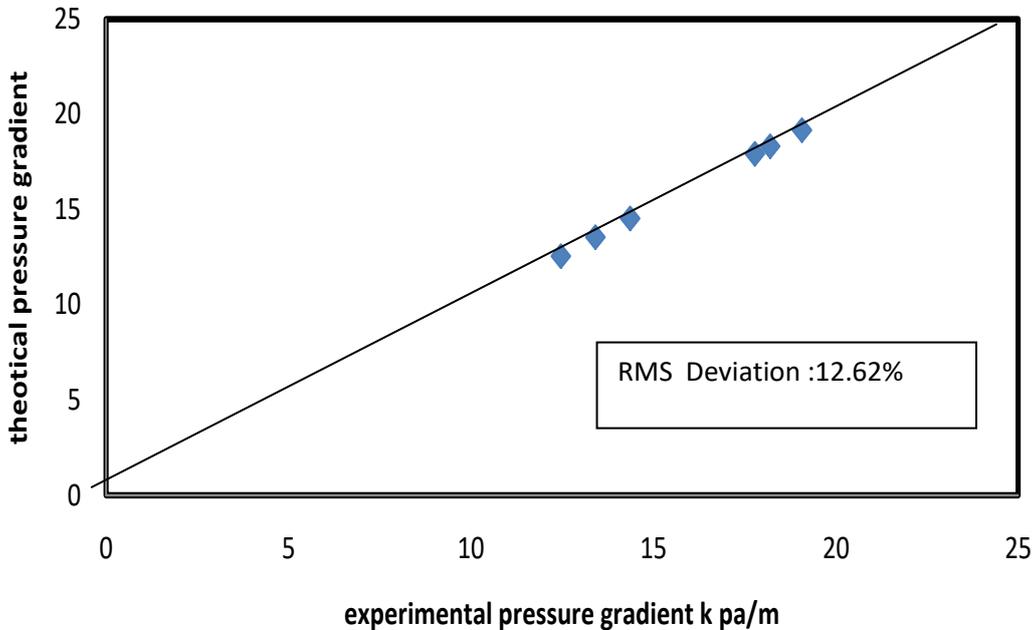


Fig.5: Comparison of experimental pressure gradient with homogeneous model in bubbly flow.

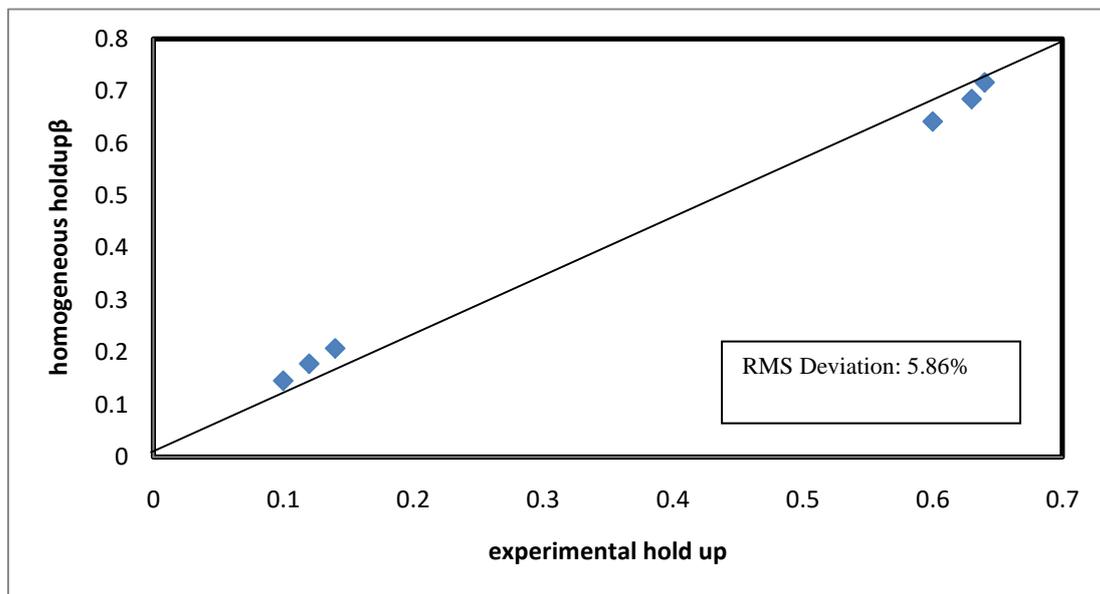


Fig. 6: Comparison of experimental hold up with homogeneous model for bubbly flow

In figure 5 and 6 maximum RMS deviation for pressure gradient and liquid holdup for bubbly flow in homogeneous model was observed. Hence drift flux model was considered. This model was proposed by Zuber and Findlay [18] which was modification of homogeneous model explains the relative motion between two phases used for predicting pressure drop in the bubbly flow pattern.

$$H_w = \frac{j_1 + j_{21}}{j} \tag{14}$$

Where j_1 , j_{21} , and j are the volumetric flux of phase 1(water), drift flux and volumetric flux of two-phase mixture, respectively. For gravity dominated flow, j_{21} is obtained from following equation.

$$j_{21} = U_\infty H_w^n (1 - H_w) \tag{15}$$

In this expression U_∞ and N for bubbly flow use from table is provided in [Wallis (1969)].

$$U_\infty = 1.18 \left(\frac{g\sigma}{\rho_w} \right)^{0.25} \tag{16}$$

And $n=2$ for bubbly flow.

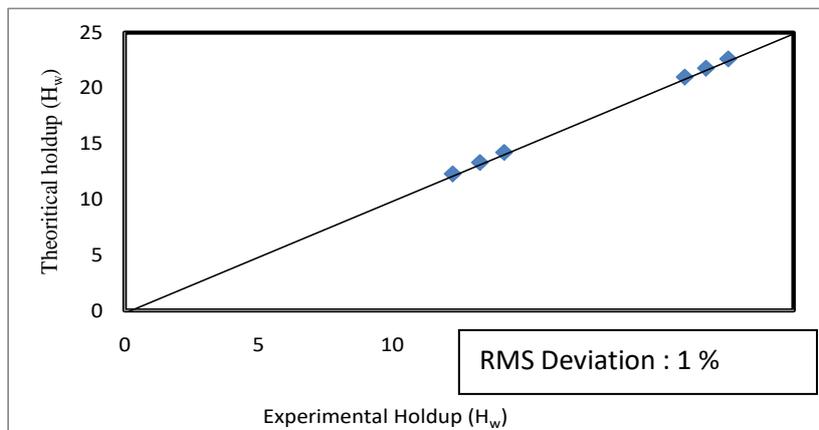


Fig. 7. Comparison of experimental holdup with the drift flux model.

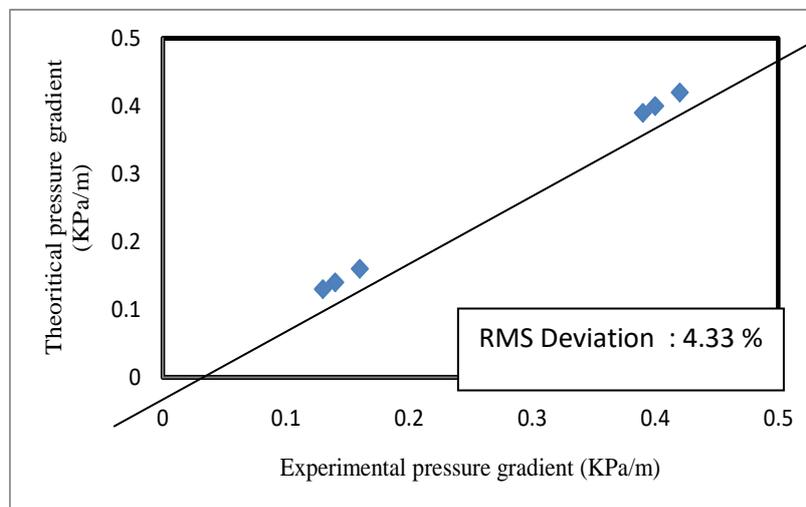


Fig. 8. Comparison of experimental pressure gradient with the drift flux model.

Water holdup thus obtained has been compared with measured holdup fig 7. Show that the reflux model is better than the homogenous model for calculating the pressure gradient and liquid holds up as it reduces the deviation for pressure gradient from 12.62% to 4.33% and liquid holdup from 5.86% to 1%.

3.4 validation of experimental pressure drop with theoretical model in slug flow

The stagnant film (SF) and moving film (MF) models were compared with each other using model equation.

a) Stagnant film (SF)

$$\Delta P_{SF} = \frac{8 V_{slug} \mu_d \alpha L}{([R - H])^2} + \frac{8 v \mu_c (1 - \alpha)L}{R^2} + \frac{L}{lu} C(3Ca)^{\frac{2}{3}} \frac{\gamma}{d} \tag{17}$$

b) Moving film (MF)

$$P_{MF} = \frac{4 V_{slug} \alpha L}{R^2 - (R - H)^2 / \mu_c + (0.5(R - H)^2) / \mu_d} + \frac{8 v \mu_c (1 - \alpha)L}{R^2} + \frac{L}{lu} C(3Ca)^{\frac{2}{3}} \frac{\gamma}{d} \tag{18}$$

The model accuracy was evaluated via the mean relative error (MRE) method,

$$MRE = \sum_{n=1}^N \frac{\Delta p_{model} - \Delta p_{experimental}}{\Delta p_{experimental}} * 100 \% \tag{19}$$

The SF and MF models were found to be in good agreement with the experimental data, from fig. 9 it can be seen that the SF values follows the same pattern as that of experimental data and is having less error as compared to the MF values. The relative difference in the prediction of the pressure drop between the SF and MF models was lower than 10%, which indicates that the film velocity has very little influence on the overall pressure drop. The sensitivity of the influence of the standard deviation of the model parameter values on the pressure drop model results was evaluated. It was found that the largest standard deviation measurement for slug velocity was found to be around 3% and difference in pressure drop was less than 19%. The largest standard deviation for dispersed phase fraction was found to be around 1%. The highest relative standard deviations taken for the slug and film velocities and film thickness gave relative differences in the pressure drop below 3%. The slug length unit, and therefore the total number of slug interfaces in the tube, has the largest influence on the pressure drop. Compared to the SF model, the MF model requires additional assumptions concerning the shear stress and the velocity throughout the interface. Therefore, the SF was chosen for the interpretation of the experimental data.

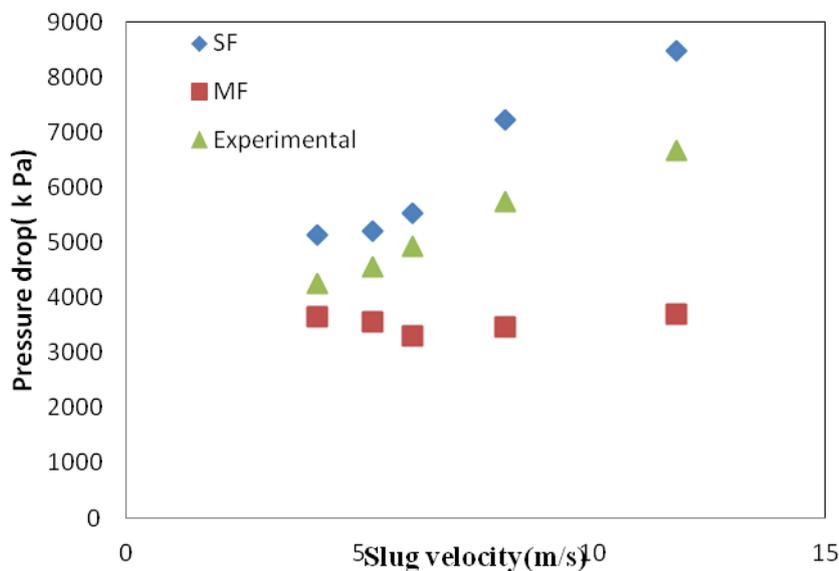


Fig. 9. Comparison of stagnant film and moving film model with experimental value in case of kerosene-water slug flow.

The individual contributions of the dispersed and continuous frictional pressure drop and the interface pressure drop to the overall pressure drop for the W-K flow in 0.006 diameter tube are shown in fig 10. The dispersed phase pressure drop was found to have the highest contribution to the overall pressure drop, with a contribution above 80%. Therefore, the correct prediction of the dispersed phase pressure drop is important to provide a high accuracy of the pressure drop estimation by the SF model. Also in fig 11. Show that there is a decrease with increase in superficial velocity of water.

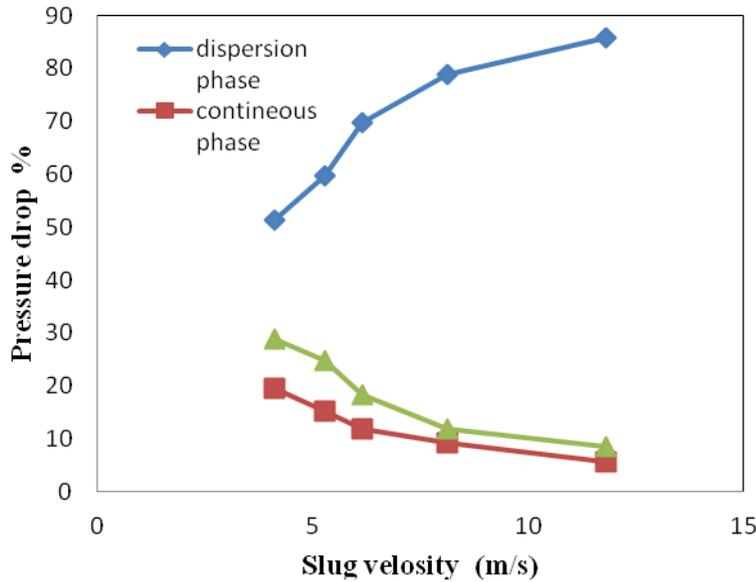


Fig. 10. Contribution of dispersed and continuous phase friction pressure drop and interfacial pressure drop to total slug flow pressure drop.

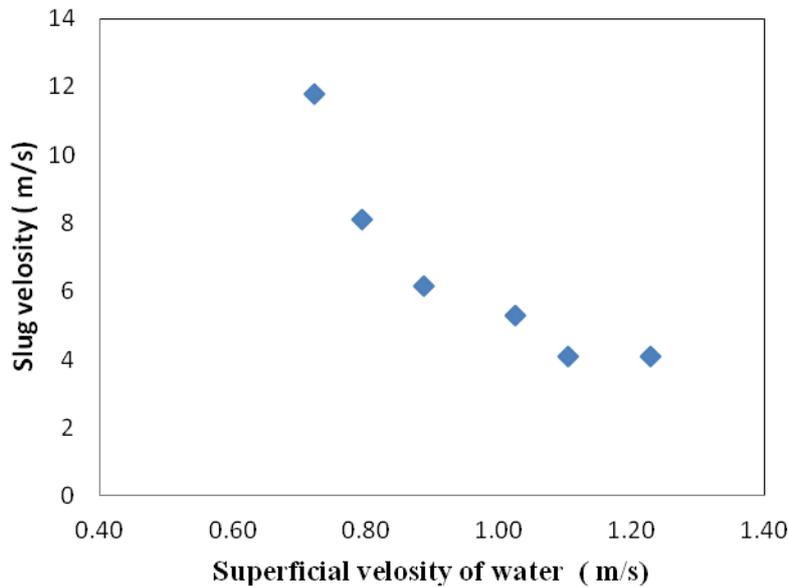


Fig. 11. Effect of superficial velocity of water in slug velocity.

IV. CONCLUSIONS

The holdup and pressure drop was measured for kerosene-water two phase flows using 0.006 m horizontal pipe. In case of hold up and pressure drop was evaluated by closing both the side of pipe and manometer. In present study model has been used to study the bubbly and dispersed flow pattern and it was found that homogeneous flow model was suited for dispersed flow pattern and drift flux model suited for bubbly flow pattern.

Two phase flow of liquid-kerosene experiment was performed by taking account of slug unit length and film thickness. Slug length and film thickness was proportional to velocity of fluid observed from trend of result also same was observed for slug length against oil/water ratio and it reveal effect of velocity and organic to aqueous ratio of fluid. Two comparable models, stagnant film model and moving film model was studied by considering effect of velocity of

fluid against pressure drop. In this experiment stagnant film was suited more as compare to moving film model. In both the model the relative error was 11 % indicates little influence of fluid velocity on pressure drop and shows good agreement of both the model.

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