Hydrodynamic Liquid-liquid Two-Phase Flow through Horizontal Pipeline

S.V.Wankhede1 P.S.Dhote2

1,2Department of Chemical Engineering

1,2Shree Guru Gobind Singhji Institute of Engineering & Technology, Vishnupuri, Nanded-431 606

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 measurements 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.

Key words: Flow, Holdup, 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.

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 rotometer of capacity of 7x10^5 m^3/s. The test section consisted of a horizontal transparent glass tube of inner diameter of 6x10^-3 m, outer diameter of 12x10^-3 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 rotometer. 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>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m³)</th>
<th>Viscosity (N s/m²)</th>
<th>Surface tension (N/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerosene</td>
<td>793</td>
<td>0.0014</td>
<td>0.014</td>
</tr>
<tr>
<td>Water</td>
<td>1000</td>
<td>0.00085</td>
<td>0.033</td>
</tr>
<tr>
<td>Water mixed with potassium dichromate</td>
<td>1592</td>
<td>0.001</td>
<td>0.065</td>
</tr>
</tbody>
</table>

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

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,

\[ H_w = \frac{V_w}{V_w + V_o} \]  
(1.1)

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.

\[ H_o = 1 - H_w \]  
(1.2)

In the present study, attempts have 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.

A. 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 decrease in diameter of pipe.
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. 2: 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.

B. 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.

1) Dispersed flow pattern

In this flow homogeneous model is suitable because of value $H_w$ and $\beta$ 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.

$$\frac{dp}{dz} = 2f \rho_m \frac{U_{sw}^2}{D}$$  \hspace{1cm} (1.5)

Above equation $\frac{dp}{dz}$, $U_{sw}$, $U_{so}$, $f$, $\rho_m$, $\rho_w$, $D$, 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 $\rho_m$ is calculated from the individual phase density using the following equation.

$$\rho_m = H_w \rho_w + H_o \rho_o$$ \hspace{1cm} (1.6)

RMS deviation is calculated by using

$$\hat{x} = \frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n}$$ \hspace{1cm} (1.7)

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

Theoretical pressure drop was determined by using following formula:

$$\Delta P = \frac{h \cdot g (\rho_m - \rho_w)}{\frac{16}{Re_m}}$$ \hspace{1cm} (1.8)

Where $h$ = difference in height of CCl$_4$ in U-tube manometer, $\rho_m$ = density of CCl$_4$, $\rho_w$ = density of water, Friction factor obtained by using following formula

$$f_m = \frac{16}{Re_m}$$ for $Re_m \leq 2100$ \hspace{1cm} (1.9)

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.

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.
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REFERENCE
