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Experimental Study of Pressure Drop Measurements of Two Phase Oil(D130)-Water Flow in Horizontal 6-inch Stainless Steel Annulus Pipe

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Abstract—**The flow of oil-water in pipes commonly occurs in oil and petroleum industries and is a challenging issue. Clear understanding of the frictional pressure drop (FPD) of oil-water flows in pipes is important for determining size of pumps and pipelines in transportation of oils.**

An experimental study investigation conducted for measurement of pressure drop of oil (D130)-water two-phase flows in 6 inch diameter horizontal stainless steel annulus pipe at different flow conditions. Two-phase large scale horizontal flow loop was used to acquire data for different water cuts and fluid mixture (oil-water) flow rates. Experiments were carried out for different water cuts (WC) ranging from 0-100% in steps of 20%. The oil-water flow rates were varied from 2000 to 12000 barrels-per-day (BPD) in steps of 2000. Exxsol mineral oil (D130) and potable water have been used as working fluids. In order to simulate field conditions, the range of liquid flow rates used matches the range of actual flow rates in oil wells. The FPD has been found to decrease initially (for all flow rates) from WC=0% to WC=20 %. Further increase in WC, causes FPD to increase from WC=20% to WC=40%. This is due to phase inversion. For a given WC=40, for increase in BPD from 6000 to 8000, increase in FPD is about 34%. The outcomes of the study will be helpful in mitigating multi-phase flow problems in oil industries.

Index Terms-Multiphase flow-loop; oil-water flow; pressure drop; water-cut; horizontal pipe

I. Introduction

The oil-water two phase flows are often witnessed in transportation of oil and water in long pipelines.

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About one third of the world's hydrocarbons are comprised of heavy oils. The exploitation of heavy oils is coupled with high transportation costs.

A sound information of factors influencing two-phase pressure drop in pipelines is desirable since considerable reduction in the pumping power needed for oil transportation (water-lubricated transportation of crude oil) can be achieved when highly viscous oil phase is surrounded by a water annulus (core annular flow scenario). This motivates and prompts research in multiphase flow domain. Considerable literature exists on the two-phase flow of oil and water.

Flow patterns, pressure gradient and phase inversion experimental data of horizontal oil–water flow in a 25.4 mm acrylic pipe has been presented by Yusuf et al. [1]. Their results show that oil viscosity has an effect on pressure gradient and the effect is more pronounced at high oil velocity. A brief review of oil-water two phase flows highlighting future research trends in horizontal pipes has been presented by Xu [2].

Talal [3] has proposed a correlation for prediction of pressure gradient with higher accuracy for horizontal oil–water separated flow (stratified and dual continuous flows). He prepared a pressure gradient database for oil–water flow which includes wide range of operational conditions, fluid properties, pipe diameters and materials.

An experimental study of high viscous ratio oil–water flow in horizontal pipes using mineral oil and tap water with density ratio of 0.9 was conducted by Sotgia et al [4]. The experiments were performed with different Pyrex and Plexiglas pipes with different diameters (21 ~ 40 mm). They have presented pressure gradients, flow pattern maps and pictures of the oil–water flow.

A comparative study of water-in-crude oil for emulsions of crude oils in a closed loop system (pipe ID2.2cm) was conducted by Jose et al. [5]. The effective viscosity of the emulsions as a function of the water fraction was calculated from pressure drop measurements. The point of inversion was observed to be fluid dependent.

The effect of air injection on liquid–liquid core annular flow of very-viscous-oil/water on the pressure drop has been experimentally conducted by Pietro et al [6]. A new data set for pressure drop was reported.

In order to efficiently transport oil, it is important to precisely model the pressure gradient of oil-water flow in pipelines. An artificial neural network model (with 0.3% error) with various inputs has been developed by Al-Wahaibi and Mjalli [7] to predict the pressure gradient of oil-water flow in horizontal pipelines.

Also, Hasanvand and Berneti [8] have utilized artificial neural networks to obtain the oil flow rate. The line pressure and temperature are inputs and output is oil flow rate. Based on experimental work, Tan et.al [9] have proposed a method to measure the phase rates of oil-water two phase flow individually in horizontal pipes.

Jing et al. [10] have studied experimentally the issue of slip between phases in water-oil two phase flows in horizontal pipes. Attention has been focused on the effects of input fluids flow rates, pipe diameter and viscosities of oil. They observed considerable deviation on holdup at low flow rates. The deviation was small at high flow rates.

Our earlier research work [11-12] on multiphase flows has focused on 4 inch diameter stainless loop/pipe. Flow rates were varied from 4000 to 8000 barrels-per-day (BPD). The present paper focuses on 6 inch diameter stainless horizontal annulus loop. The working fluids are Exxsol D130 Mineral Oil and water. The inlet oil-water flow rates have been varied from 2000 to 12000 BPD (to simulate field conditions). Water cuts (WC) have been varied from 0-100%. The basic infra-structure of earlier papers and present work is same but flow loops are different. The change in diameter of the flow loop changes flow behavior and makes all the difference and has a remarkable effect on flow characteristics. The motivation for world-wide extensive multiphase research is due to widespread occurrence of flows in pipes. Understanding of the FPD of oil-water flows in pipes is important for sizing of pumps and pipelines in transportation of oils. The outcomes of the study will be helpful in mitigating multi-phase flow problems related to oil-petroleum industries and to reduce pumping power in transportation of oil from oil wells. The paper deals with challenges associated in transportation of oil in horizontal 6" inch diameter stainless annulus pipes. To the best of our knowledge, the present specific research work is first of its kind and is not available in literature.

In the light of the above literature survey, there is no work available on pressure drop measurements of oil (D130)-water two-phase annulus flow in horizontal 6 inch diameter stainless steel pipe at different flow conditions. This is the driving force for the present experimental study and it focuses on the effect of flow rates, water-cuts on pressure drop measurements of oil (D130)-water two-phase annulus flow.

In this study, efforts have been made to present pressure drop measurements of oil (D130)-water two-phase flow in a horizontal 6 inch diameter stainless steel annulus pipe at different flow conditions. Specifically, eexperiments were conducted for different water cuts; 0%, 20%, 40% 60% 100%. Inlet oil-water flow rates were varied from 2000 to 12000 BPD to simulate field conditions.

II. Experimental setup

The Oil-water two phase experiments were carried out at the large scale multi-phase flow laboratory of King Fahd University of Petroleum and Mineral, Dhahran, Saudi Arabia [11].

The layout of the flow loop is presented in Figure 1. Experimental set-up consists of: four centrifugal variable speed pumps [2 pumps for water (WP) and 2 pumps for oil, (OP)], 6 inch stainless annulus loop, a horizontal separator tank (WOST), which serves as a storage tank, two level indicators for oil and water each. The loop is mounted on swinging platform (angle can be varied from 0° - 90°). The fixing of loop at a given angle is done by flexible connection (FC).

The instruments of the loop include: a turbine type oil flow meter (OFM), a turbine type water flow meters (WFM), line pressure transmitter (LPT), two flow differential pressure transmitters (DPT1 and DPT2). More information of the loop components and instruments is given in Table 1. [12].

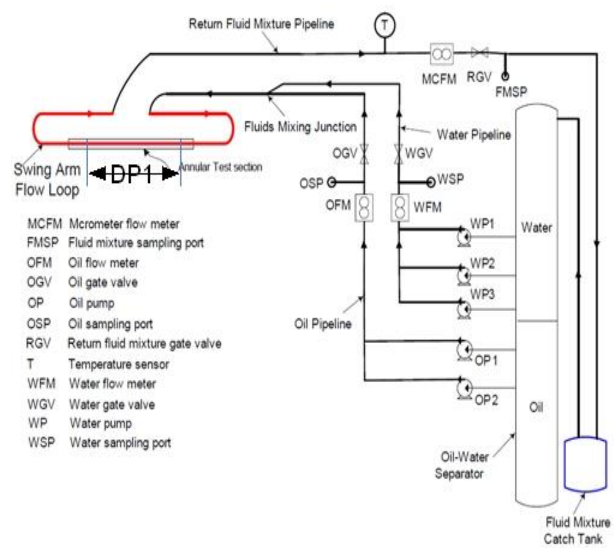

Figure 1. Schematic layout of the oil-water multiphase flow loop

TABLE I. Details of equipment of the flow loop

Items	Manufacture r	Model	Capacit y/Range	Accura cy/Erro r
Four pumps (two water, two oil)	NEWAR FLOW SERVE	50-32CPX200	35 m3/hr	-
Two turbine flow meter	Omega	EF10	±10 m/s	±1.0 %
Line pressure gauge	ROSEMOUNT	AOB-20	0-7 bar	±0.25%
DPT1	ROSEMOUNT	300S2EAE5 M9	0-70 inches of water	±0.1%
DPT2	ROSEMOUNT	300S2EAE5 M9	0-12 inches of water	±0.1%
Four pumps (two water, two oil)	NEWAR FLOW SERVE	50-32CPX200	35 m3/hr	-

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III. Experimental procedure

As a starting point, experiments were first conducted for water-only and oil-only single phase to validate the pressure drop measurements against available empirical models, and to ascertain effectiveness of pressure transmitters and flow meters of the loop.

To achieve this, water was pumped in the loop using centrifugal pumps. The desired volume flow rate was obtained by varying speed of pumps through variable speed drives and also by regulating oil globe valve (OGV) and water globe valve (WGV) of oil and water flow streams respectively. The flow rates on the discharge line of the pumps were measured by Turbine flow meters. The required outlet pressure (e.g. 1 bar or 2 bars) of the loop is set by throttling the Return gate valve (RGV, Figure1).

The experiments were carried out for a given flow rate and differential pressure measurements were recorded along 1m annulus pipe length (after achieving the steady state flow condition). The experimental data was recorded using CR 1000 data logger. The above procedure was repeated for oil-only flow experiments.

The friction factor was calculated from the experimentally obtained pressure drop and this friction factor was compared with friction factors obtained from Blasius and Zigrang & Sylvester 1985 correlations. A close matching has been found specifically with the Blasius friction factor. The related equations and graphs are reported in our earlier studies [11-12].

For a given oil-water two phase flow (for a given angle, 0° case), speeds of the oil and water pumps were varied to achieve required flow rate and water cut. Once the required water cut and flow rates are reached, pressure drop [across 1m (DP1)] measurements were made. Similar procedure was followed for different water cut ratios and for different inlet oil-water flow rates.

IV. Results and discussions

Oil-water multiphase flow experiments were conducted for different water cut ratios (0%, 20%, 40%, 60% and 100%). Inlet oil-water flow rates were varied from 2000 to 12000 BPD.

A. *Effect of water-cut on oil-water pressure drop for different flow rates*

Figure 2 shows the effect of water cut for different flow rates on pressure drop. It can be seen from this Figure that the frictional pressure drop has been found to decrease initially (for all flow rates) from WC=0% to WC=20%. Further increase in WC (for all flow rates), frictional pressure drop has been found to increase from WC=20% to WC=40%. The behavior is stable (or decreases slightly) after WC=40%. This could be due phase inversion or change in flow pattern regime. Also, it can be observed from Figure 2, that at any given WC, the frictional pressure drop increases with increase in flow rate. For a given water cut WC=40%, increasing in BPD from 6000 to 8000, percentage increase in FPD is about 34%.

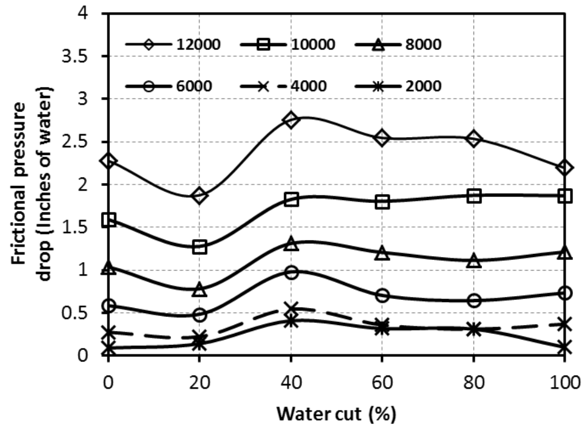

Figure 2. Effect of water cut on Frictional pressure drop for different flow rates for oil-water flow.

B. *Effect of flow rate on oil-water pressure drop for different water-cuts*

Figure 3 shows the effect of flow rate on frictional pressure drop for different water cuts. It can be seen from Figure 3, pressure drop increases with flow rate. The frictional pressure has been found to increase linearly with respect flow rate. However, effect of water cut on FPD is not linear. For a given flow rate 10000 BPD, increase in water cut from WC 20% to 40%, percentage increase in frictional pressure drop is about 43%.

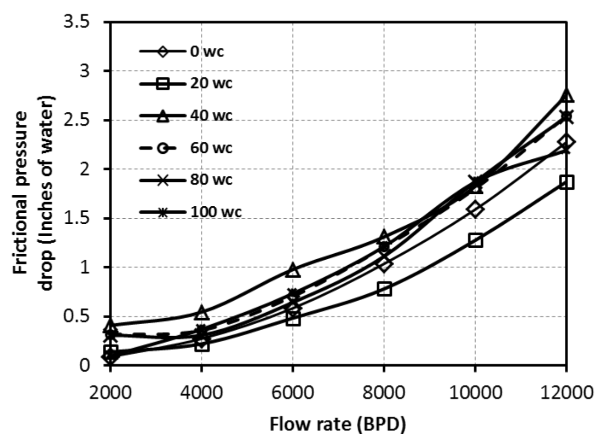

Figure 3. Effect of flow rates on Frictional pressure drop for different water cuts for oil-water flow.

V. Conclusion

In the present study, pressure drop measurements of oil (D130)-water two-phase flow in a horizontal 4″ diameter stainless steel annulus pipe at different flow conditions were made. Experiments were conducted for different water cut ratios (0%, 20%, 40%, 60% and 100%). Inlet oil-water flow rates were varied from 2000 to 12000 BPD. In order to validate the experimental work, measured pressure drops and friction factor of single phase oil and single phase water were compared with existing empirical relations and good agreement was found.

For a given water cut WC=40, with increase in BPD from 6000 to 8000, percentage increase in frictional pressure drop is about 34%. The FPD has been found to increase linearly with respect flow rate. However, effect of water cut on frictional pressure drop is not linear.

For a given flow rate 10000 BPD, increase in water cut from WC 20% to 40%, percentage increase in frictional pressure drop is about 43%. The outcomes of the study aid to understand factors influencing two phase pressure drop and enhance the confidence level of the oil and gas industries personnel in mitigating the FPD loss issues of oil (D130)-water two-phase flow systems.

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