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Experimental Investigation of Effect of Flow Conditions on Pressure Drop of Two Phase Oil (D130)-Water Flow in Horizontal and Vertical 6-inch Annulus Pipe

Syed M. Shaahid[1,*], Luai M. Alhems[1], A. Ahmad[1], Mehaboob Basha[1], A. M. Al-Sarkhi[1], M. O. Elobeid[1], J. J. Xiao[2], Rafael Lastra[2], Chidirim E.[2]

[1] Applied Research Center for Metrology, Standards & Testing, Research Institute, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia
[2] Saudi Aramco, Dhahran, Saudi Arabia

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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 investigation has been conducted for measurement of pressure drop of oil Exxsol (D130)-water two-phase flow in 6 inch diameter horizontal and vertical stainless steel annulus pipe at different flow conditions. Two-phase large scale horizontal & vertical 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% and for different inclination angles (0° and 90°). The oil-water flow rates were varied from 2,000 to 12,000 barrels-per-day (BPD). 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 frictional pressure drop (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 6,000 to 8,000, increase in FPD is about 34%. The effect of angle has found to be appreciable. For a given flow rate 8,000 BPD & WC=40%, for increase in angle from 0 to 90°, percentage increase in frictional pressure drop is about 26%. The outcomes of the study will be helpful in mitigating multi-phase flow problems in oil and petroleum industries.

1. Introduction

The oil-water two phase flows are often witnessed in transportation of oil and water in long pipelines. About one third of the world's hydrocarbons are comprised of heavy oils. The exploitation of heavy oils is coupled with high transportation costs.

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[*] *Corresponding author.*
E-mail address: mshaahid@kfupm.edu.sa

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A sound knowledge of factors influencing two-phase flow 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 research in multiphase flow domain. Considerable literature exists on the two-phase oil-water flow.

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].

Al-Wahaibi [3] has proposed a correlation for prediction of pressure gradient with higher accuracy for horizontal oil–water separated flow (stratified and dual continuous flows). Pressure gradient database was prepared 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 ID 2.2 cm) was conducted by Plasencia *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 carried out experimentally by Poesio *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.

Hasanvand and Berneti [8] have also utilized artificial neural networks to obtain the oil flow rate. The line pressure and temperature are inputs and output are 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. Xu *et al.,* [10] have studied experimentally the issue of slip between phases in water-oil two phase flows in horizontal pipes. Attention was 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.

In order to study the characteristics vertical oil-water two phase flows (in 20 mm diameter pipe), Du *et al.,* [11] carried out several experiments. Flow pattern map of oil water for different superficial velocities have been shown. A research study on three phase flow in vertical pipes was performed by Descamps *et al.,* [12] with emphasis on phase inversion. They concluded that the size of the gas bubble produced during experiments depends on water dispersion.

An experimental study on oil/water flow in horizontal and slightly inclined plexi glass tubes (with 21 mm ID, 9m long) was conducted by Strazza *et al.,* [13]. The emphasis was on core-annular flow behavior, pressure drops, and oil hold-up measurements. Good agreement was noticed between experimental data and other models. High viscosity two phase liquid-liquid flow experiments in horizontal and slightly inclined pipes were conducted by Grassi *et al.,* [14]. The results were validated against theoretical models.

Also, experiments were conducted by Grolmann and Fortuin [15] with focus on liquid hold-up and pressure gradient in gas-liquid flow in slightly inclined pipes. Effect of inclination was found to be appreciable at low gas flow rates. The effect of phase inversion on pressure gradient in dispersed flow of two immiscible (water and oil) liquids for steel and acrylic pipes (60 and 32 mm ID) for various mixture velocities was conducted by Ioannou *et al.,* [16]. For all studies cases, large increase in pressure gradient was observed before phase inversion, which sharply reduces after occurrence of new continuous phase.

Flow measurement of oil-in-water fluid flow is complex and challenging issue. A new method of two-phase flow metering has been proposed by Faraj *et al.,* [17]. The method is based on the use of dual-modality system and multidimensional data fusion. To validate the proposed method, experiments were conducted on a vertical upward oil-in-water pipe flow (50mm inner-diameter test section) at different total liquid flow rates spanning the range of 8–16 m^3/hr.

The local flow characteristics of oil–water dispersed flow in a vertical upward pipe were studied experimentally for different oil-water velocity by Zhao *et al.,* [18]. The typical radial profiles of interfacial area concentration, oil phase fraction, interfacial velocity, and oil pressure drops have been presented.

The impact of uphill and downhill pipe inclinations on the flow patterns, hold up and pressure gradient during two-liquid phase flows various mixture velocities and phase fractions has been explored experimentally by Lum *et al.,* [19]. It was observed that the oil to water velocity ratio was higher for the upward than for the downward flows but in many cases, oil was flowing faster than water for all inclinations. More recent research studies related to dispersion, flow & angle, pressure drop & angle, flow related parameters, phase-change, flow-pattern and void-fraction, oil-gas-water issues, drag resistance by pressure drop, etc. are available in references [20-25].

Our earlier research work on multiphase flows has focused attention on 4 inch diameter stainless loop/pipe [26,27]. Flow rates were varied from 4,000 to 8,000 barrels-per-day (BPD). The present paper focuses on 6 inch diameter stainless steel horizontal and vertical annulus loop/pipe. The working fluids are Exxsol D130 Mineral Oil and water. The inlet oil-water flow rates have been varied from 2,000 to 12,000 BPD in steps of 2,000 (to simulate/imitate field conditions). Water cuts (WC) have been varied from 0-100% (in steps of 20%). The basic infra-structure (research facility) of earlier papers and present work is same but sizes of flow loops are different. The change in diameter of the flow loop changes flow behavior considerably and has a appreciable effect on flow characteristics. The motivation for extensive multiphase research (globally) 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 (through horizontal and vertical pipelines). The paper deals with challenges associated in transportation of oil in horizontal and vertical 6” inch diameter stainless annulus pipes. Considerable papers related to smaller diameter pipes are available in literature but papers related to bigger diameter loops are not available. To the best of our knowledge, the present specific research work is first of its kind.

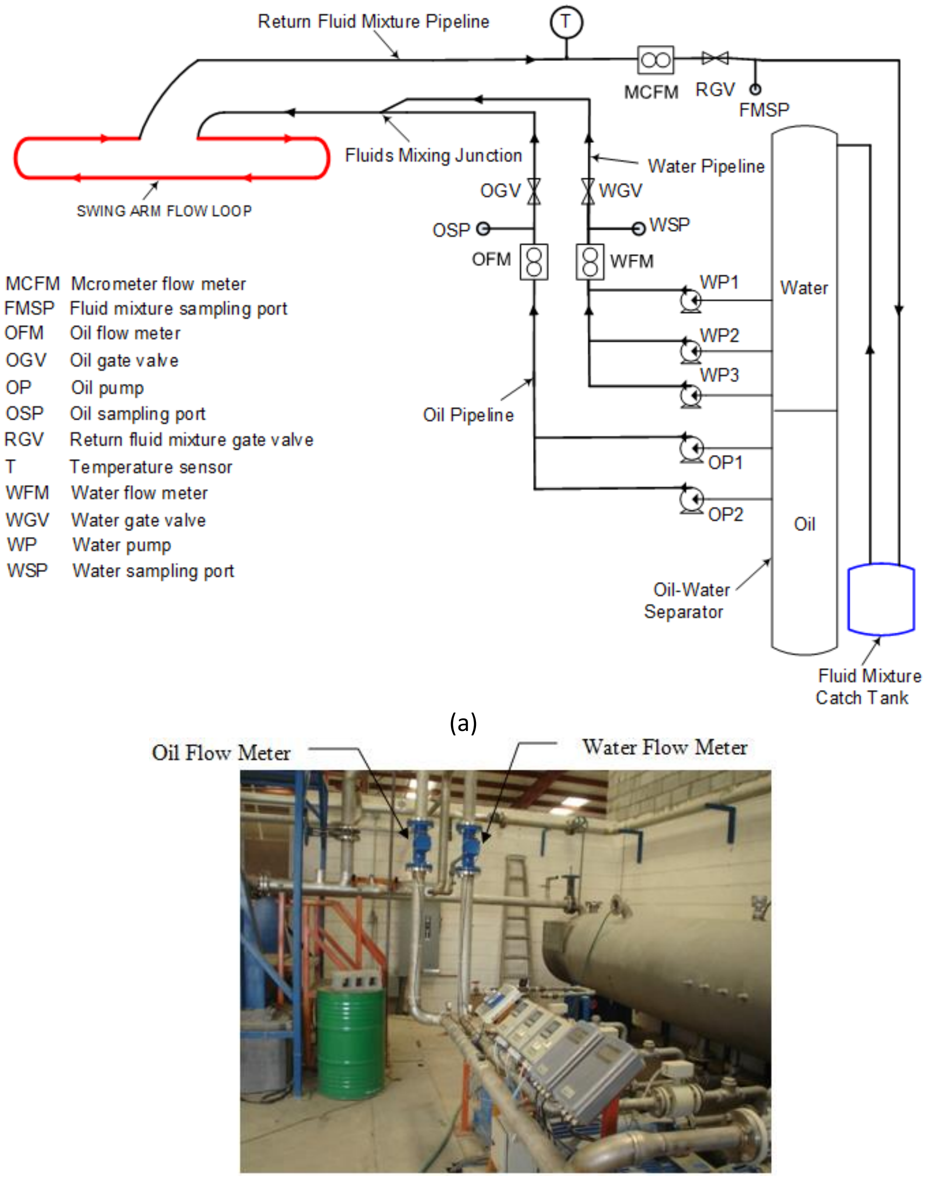
In the light of the above literature survey, there is no work available on pressure drop measurements of Exxsol oil (D130)-water two-phase annulus flow in horizontal and vertical 6 inch diameter stainless steel pipe at different flow conditions. This is the driving force for the present experimental study and it focuses on the effect of flow rates, water-cuts, and inclination angles 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 and vertical 6 inch diameter stainless steel annulus pipe at different flow conditions. Specifically, experiments were conducted for different water cuts; 0%, 20%, 40% 60% 100% and different inclination angles (0° and 90°). Inlet oil-water flow rates were varied from 2,000 to 12,000 BPD (in steps of 2,000) to simulate field conditions.

2. Experimental Setup

The oil-water two phase flow experiments were carried out in the large scale multi-phase flow laboratory of King Fahd University of Petroleum and Mineral, Dhahran, Saudi Arabia [26].

The layout of the flow loop is presented in Figure 1. Experimental set-up consists of: five centrifugal variable speed pumps [2 pumps for water (WP), 2 pumps for oil (OP), one extra water pump (to cover additional flow-rates/BPD or to be used as standby unit if one of the pump malfunctions)], 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°).



(a)

(b)

Fig. 1. (a) Schematic layout of the oil-water multiphase flow loop, (b) Picture of the oil-water multiphase flow facility

The instruments of the loop include: a turbine type oil flow meter (OFM), a turbine type water flow meter (WFM), line pressure transmitter (LPT), flow differential pressure transmitter (DP1, located in the swing arm flow loop). More information of the loop components and instruments is given in Table 1 [27]. Properties of mineral oil Exxsol D130 are listed in Table 2.

Table 1
Details of equipment of the flow loop

Items	Manufacturer	Model	Capacity/Range	Accuracy/Error
Four pump (two water, two oil)	NEWAR FLOW SERVE	50-32CPX200	35 m^3/hr	-
Two turbine flow meters	Omega	EF10	±10 m/s	±1.0 %
Line pressure gauge	ROSEMOUNT	AOB-20	0-7 bar	±0.25%
DP1	ROSEMOUNT	300S2EAE5M9	0-70 inches of water column	±0.1%

Table 2
Physical properties of the Exxsol D130 mineral oil

Properties	EXXSOL D130	Units	Test Based On
Initial Boiling Point (IBP)	279	°C	N/A
Dry Point (DP)	313	°C	N/A
Flash Point (Method A)	140	°C	ASTM D93
Aromatic Content	1.0	wt%	ExxonMobil Method
Density (15.6°C)	827	kg/m3	ASTM D4052
Vapor Pressure (20.0°C)	< 0.0402	Inch H2O	ExxonMobil Method
Aniline Point (Method E)	88	°C	ASTM D611
Kinematic Viscosity (25.0°C)	6.89*10-6	m^2/s	ASTM D445

3. Experimental Procedure

Discussion on integrity and validation of outcomes of the loop/facility has been covered in appreciable depth in our earlier studies [26,27]. In the earlier studies, the 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 [26,27]. The friction factor was calculated from the experimentally obtained pressure drop (*for 4" pipe*) and this friction factor was compared with friction factors obtained from Blasius and Zigrang & Sylvester correlations (*for 4" pipe*). A close matching has been found. All related details and equations are provided in the above references.

In the light of the above discussion, friction factor calculation based on experimentally obtained pressure drop (*for 6" pipe*) is considered to be comparable with friction factors obtained from Blasius and Zigrang & Sylvester correlations (*for 6" pipe*). There may be some discrepancies due to operational inconsistencies.

Regarding the present experimental work, for a given oil-water two phase flow (for a given angle, 0° & 90° cases), 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.

To achieve the above, water and oil were pumped in the loop using centrifugal pumps. The desired volume flow rate was obtained by varying speed of pumps through variable speed drives and 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, Figure 1).

The experiments were carried out for a given flow-rate/water-cut/angle and differential pressure measurements were recorded along 1 m annulus pipe length (after achieving the steady state flow condition).

4. 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 2,000 to 12,000 BPD. The experiments were carried out for horizontal and vertical (90° inclination angle) orientations of the flow loop.

4.1 Effect of Water-Cut and Flow Rates on Oil-Water Pressure Drop for Different Inclinations

Figure 2(a) shows the effect of water cut for different flow rates on pressure drop (0° case). It can be seen from this figure that the frictional pressure drop (FPD) 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 fluctuates slightly) after WC=40%. This could be due phase inversion or change in flow pattern regime. Also, it can be observed from Figure 2(a), that at any given WC, the frictional pressure drops increase with increase in flow rate. For a given water cut WC=40%, increasing in BPD from 6,000 to 8,000, percentage increase in FPD is about 34%.

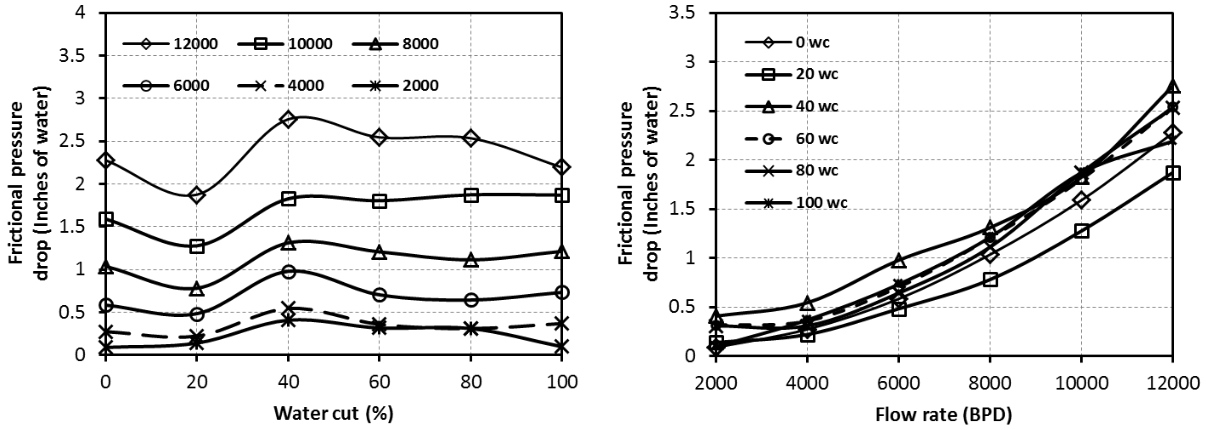
Phase Inversion (in oil-water flow systems), refers to a phenomenon where, with a small change in the operational conditions, dispersion of oil drops in water (Do/w) becomes dispersion of water drops in oil (Dw/o) or vice-versa. The associated pressure drops changes abruptly at or near phase inversion point (PIP). In general, in the present study, this has been observed at WC=40%.

Figure 2(b) shows the effect of flow rate on frictional pressure drop for different water cuts (0° case). It can be seen from Figure 2(b), pressure drop increases with flow rate. The frictional pressure has been found to increase linearly with respect flow rate. For a given flow rate of 10,000 BPD, increase in water cut from WC 20% to 40%, increase in frictional pressure drop is about 43%.

For a given angle ($\theta = 90°$), the effect of water cut for different flow rates on pressure drop is shown in Figure 3(a). As it can be seen from Figure 3(a), the frictional pressure drop has been found to increase from WC=20% to WC=40% (for most of the flow rates). For a given flow rate, the FPD is maximum at WC=40%. This could be due to phase inversion as discussed above. Also, it can be observed from Figure 3(a), for WC=40%, with increase in BPD from 6,000 to 8,000, percentage increase in frictional pressure drop is about 45%.

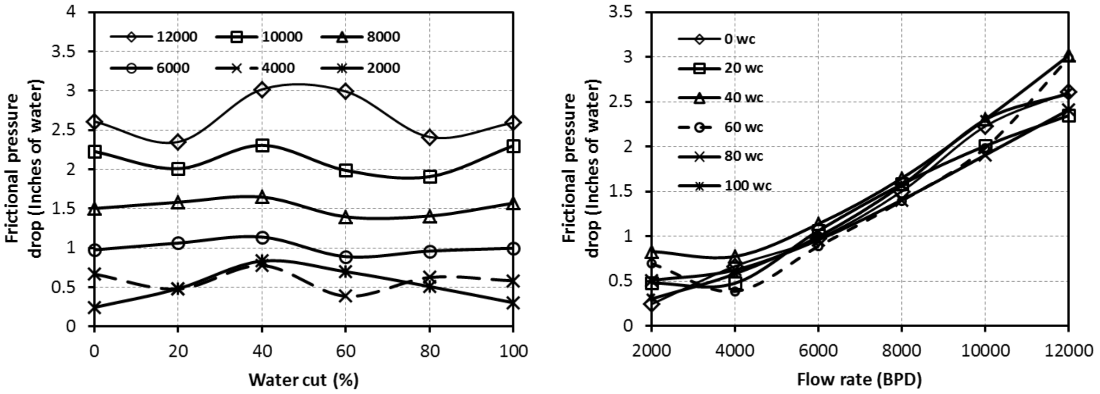
For a given angle ($\theta = 90°$), the effect of flow rate on frictional pressure drop for different WC is shown in Figure 3(b). As it can be seen from Figure 3(b), pressure drop increases with flow rate and

WC. The FPD drop has been found to increase linearly with respect flow rate. For a given flow rate of 12,000 BPD, for increase in water cut from WC=20% to 40%, percentage increase in FPD is about 28%.



(a) (b)

Fig. 2. Frictional pressure drop behavior. (a) Effect of water cut on pressure drop for different flow rates, (b) Effect of flow rate on pressure drop for different water cuts (0° case)



(a) (b)

Fig. 3. Frictional pressure drop behaviour. (a) Effect of water cut on pressure drop for different flow rates, (b) Effect of flow rate on pressure drop for different water cuts (90° case)

4.2 Effect of Inclination on Oil-Water Pressure Drop for Different Flow Rates for Given Water Cut

For the sake of understanding/demonstration, the angle effect on FPD for different flow rates, has been presented for a given water cut (WC = 40%).

For a given water cut (WC = 40%), the effect of inclination for different flow rates on pressure drop is shown in Figure 4. In general (for the investigated angles), pressure drop increases with flow rate and inclination. The effect of angle has found to be appreciable. For a given flow rate 8,000 BPD, WC = 40%, for increase in angle from 0 to 90°, percentage increase in frictional pressure drop is about 26%.

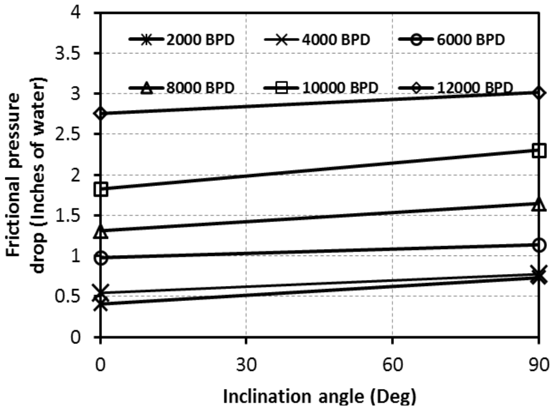


Fig. 4. Effect of angle on pressure drop for different flow rates (for a given water cut, WC = 40%)

5. Conclusions

The present experimental work has focused attention on the pressure drop measurements of Exxsol oil (D130)-water two-phase flow in a horizontal and vertical 6 inch diameter stainless steel annulus pipe at different flow conditions. Experiments were conducted for different inclination angles (including; 0°, 90°) and for different water cut ratios (0%-100%). Inlet oil-water flow rates were varied from 2,000 to 12,000 BPD.

For a given water cut WC=40% (θ=0°), with increase in BPD from 6,000 to 8,000, percentage increase in frictional pressure drop is about 34%.

For a given water cut WC=40% (θ = 90°), increase in BPD from 6,000 to 8,000, percentage increase in frictional pressure drop is about 45%.

For a given flow rate (θ=0°, θ=90°), the FPD is maximum at WC=40%. This could be due to phase inversion.

The effect of angle has found to be appreciable. For a given flow rate 8,000 BPD (for WC= 40%), with increase in angle from 0 to 90°, percentage increase in frictional pressure drop is about 26%.

The outcomes of the study aid to understand factors influencing two phase flow 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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References

[1] Yusuf, N., Y. Al-Wahaibi, T. Al-Wahaibi, A. Al-Ajmi, A. S. Olawale, and I. A. Mohammed. "Effect of oil viscosity on the flow structure and pressure gradient in horizontal oil-water flow." *Chemical Engineering Research and Design* 90, no. 8 (2012): 1019-1030. https://doi.org/10.1016/j.cherd.2011.11.013

[2] Xu, Xiao-Xuan. "Study on oil-water two-phase flow in horizontal pipelines." *Journal of Petroleum Science and Engineering* 59, no. 1-2 (2007): 43-58. https://doi.org/10.1016/j.petrol.2007.03.002

[3] Al-Wahaibi, Talal. "Pressure gradient correlation for oil-water separated flow in horizontal pipes." *Experimental Thermal and Fluid Science* 42 (2012): 196-203. https://doi.org/10.1016/j.expthermflusci.2012.04.021

[4] Sotgia, Giorgio, Paolo Tartarini, and Enrico Stalio. "Experimental analysis of flow regimes and pressure drop reduction in oil-water mixtures." *International Journal of Multiphase Flow* 34, no. 12 (2008): 1161-1174. https://doi.org/10.1016/j.ijmultiphaseflow.2008.06.001

[5] Plasencia, Jose, Bjørnar Pettersen, and Ole Jørgen Nydal. "Pipe flow of water-in-crude oil emulsions: Effective viscosity, inversion point and droplet size distribution." *Journal of Petroleum Science and Engineering* 101 (2013): 35-43. https://doi.org/10.1016/j.petrol.2012.11.009

[6] Poesio, Pietro, Domenico Strazza, and Giorgio Sotgia. "Very-viscous-oil/water/air flow through horizontal pipes: Pressure drop measurement and prediction." *Chemical Engineering Science* 64, no. 6 (2009): 1136-1142. https://doi.org/10.1016/j.ces.2008.10.061

[7] Al-Wahaibi, Talal, and Farouq S. Mjalli. "Prediction of horizontal oil-water flow pressure gradient using artificial intelligence techniques." *Chemical Engineering Communications* 201, no. 2 (2014): 209-224. https://doi.org/10.1080/00986445.2013.766603

[8] Hasanvand, M., and S. M. Berneti. "Predicting oil flow rate due to multiphase flow meter by using an artificial neural network." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 37, no. 8 (2015): 840-845. https://doi.org/10.1080/15567036.2011.590865

[9] Tan, Chao, Wei Dai, Hoi Yeung, and Feng Dong. "A Kalman estimation based oil-water two-phase flow measurement with CRCC." *International Journal of Multiphase Flow* 72 (2015): 306-317. https://doi.org/10.1016/j.ijmultiphaseflow.2014.06.014

[10] Xu, Jing-yu, Ying-xiang Wu, Fei-fei Feng, Ying Chang, and Dong-hui Li. "Experimental investigation on the slip between oil and water in horizontal pipes." *Experimental Thermal and Fluid Science* 33, no. 1 (2008): 178-183. https://doi.org/10.1016/j.expthermflusci.2008.07.011

[11] Du, Meng, Ning-De Jin, Zhong-Ke Gao, Zhen-Ya Wang, and Lu-Sheng Zhai. "Flow pattern and water holdup measurements of vertical upward oil-water two-phase flow in small diameter pipes." *International Journal of Multiphase Flow* 41 (2012): 91-105. https://doi.org/10.1016/j.ijmultiphaseflow.2012.01.007

[12] Descamps, M. N., R. V. A. Oliemans, G. Ooms, and R. F. Mudde. "Experimental investigation of three-phase flow in a vertical pipe: Local characteristics of the gas phase for gas-lift conditions." *International Journal of Multiphase Flow* 33, no. 11 (2007): 1205-1221. https://doi.org/10.1016/j.ijmultiphaseflow.2007.06.001

[13] Strazza, Domenico, Benedetta Grassi, Marco Demori, Vittorio Ferrari, and Pietro Poesio. "Core-annular flow in horizontal and slightly inclined pipes: Existence, pressure drops, and hold-up." *Chemical Engineering Science* 66, no. 12 (2011): 2853-2863. https://doi.org/10.1016/j.ces.2011.03.053

[14] Grassi, B., D. Strazza, and P. Poesio. "Experimental validation of theoretical models in two-phase high-viscosity ratio liquid-liquid flows in horizontal and slightly inclined pipes." *International Journal of Multiphase Flow* 34, no. 10 (2008): 950-965. https://doi.org/10.1016/j.ijmultiphaseflow.2008.03.006

[15] Grolman, Eric, and Jan M. H. Fortuin. "Gas-liquid flow in slightly inclined pipes." *Chemical Engineering Science* 52, no. 24 (1997): 4461-4471. https://doi.org/10.1016/S0009-2509(97)00291-1

[16] Ioannou, Karolina, Ole Jorgen Nydal, and Panagiota Angeli. "Phase inversion in dispersed liquid-liquid flows." *Experimental Thermal and Fluid Science* 29, no. 3 (2005): 331-339. https://doi.org/10.1016/j.expthermflusci.2004.05.003

[17] Faraj, Yousef, Mi Wang, Jiabin Jia, Qiang Wang, Cheng-gang Xie, Gary Oddie, Ken Primrose, and Changhua Qiu. "Measurement of vertical oil-in-water two-phase flow using dual-modality ERT-EMF system." *Flow Measurement and Instrumentation* 46 (2015): 255-261. https://doi.org/10.1016/j.flowmeasinst.2015.08.010

[18] Zhao, Dongjian, Liejin Guo, Xiaowei Hu, Ximin Zhang, and Xin Wang. "Experimental study on local characteristics of oil-water dispersed flow in a vertical pipe." *International Journal of Multiphase Flow* 32, no. 10-11 (2006): 1254-1268. https://doi.org/10.1016/j.ijmultiphaseflow.2006.06.004

[19] Lum, JY-L., T. Al-Wahaibi, and P. Angeli. "Upward and downward inclination oil-water flows." *International Journal of Multiphase Flow* 32, no. 4 (2006): 413-435. https://doi.org/10.1016/j.ijmultiphaseflow.2006.01.001

[20] Musa, Solihin, Nor Azwadi Che Sidik, Siti Nurul Akmal Yusof, and Erdiwansyah. "Analysis of Internal Flow in Bag Filter by Different Inlet Angle." *Journal of Advanced Research in Numerical Heat Transfer* 3, no. 1 (2020): 12-24.

[21] Sahak, Ahmad Sofianuddin A., Nor Azwadi Che Sidik, and Siti Nurul Akmal Yusof. "A Brief Review of Particle Dispersion of Cavity Flow." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 20, no. 1 (2020): 27-41. https://doi.org/10.37934/araset.20.1.2741

[22] WafirulHadi, Mohamad, Titin Trisnadewi, and Nandy Putra. "Thermal Management System Based on Phase Change Material (PCM) and Heat Pipe in Lithium-ion Electric Vehicle Batteries." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 3, no. 1 (2021): 26-35.

[23] Bacirheba, Mugisho Joel, Tanoh Boguy Eddy Martial, Mirsamiev Narzullo Abdugaforovich, and Madumarov Mukhriddin Mukhammadjon Ugli. "Time Estimation of Gas-Water Contact Lift using Response Surface Analysis in Yamburg Gas Field Conditions." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 22, no. 1 (2021): 46-53. https://doi.org/10.37934/araset.22.1.4653

[24] Sudarja, Sudarja, and Sukamta Sukamta. "Experimental Study on Flow Pattern and Void Fraction of Air-Water and 3% Butanol Two-Phase Flow in 30° Inclined Mini Channel." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 1, no. 1 (2020): 11-20.

[25] Gunawan, Gunawan, Yanuar Yanuar, A. S. A. Utomo, F. Fariz, and S. A. Lambang. "Reduction of Drag Resistance by Pressure Drop in Pipeline with 3-Dimensional Design Optimization." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 1, no. 1 (2020): 1-10.

[26] Sukamta, Sukamta, Noviyanto Noviyanto, Sudarja Sudarja, and Sri Sundari. "Characteristics of Void Fraction Using Image Processing of Two-Phase Flow of Air-Pure Water and Glycerin (40-70%) on A Transparent Mini Pipe with Slope of 45° to the Horizontal." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 1, no. 1 (2020): 29-37.

[27] Basha, Mehaboob, S. M. Shaahid, and Luai M. Al-Hems. "Effect of Water Cut on Pressure Drop of Oil (D130)-Water Flow in 4 ″Horizontal Pipe." In *IOP Conference Series: Materials Science and Engineering*, vol. 326, no. 1, p. 012002. IOP Publishing, 2018. https://doi.org/10.1088/1757-899X/326/1/012002

[28] Shaahid, S. M., Mehaboob Basha, and Luai M. Al-Hems. "Experimental investigation of two-phase oil (d130)-water flow in 4 ″pipe for different inclination angles." In *IOP Conference Series: Materials Science and Engineering*, vol. 326, no. 1, p. 012013. IOP Publishing, 2018. https://doi.org/10.1088/1757-899X/326/1/012013