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Parametric Study on Venturi Pressure Drop for Two Phase Oil (D130)-Water Flow for Different Operating Conditions – An Experimental Investigation

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ABSTRACT

The governing parameters which affect pressure drop of two-phase oil-water flow across the venturi meter are water cut and angle of inclination. The study investigates experimentally the effect of inclination and water cut on pressure drop measurements across different venturi meters with beta ratios (β) = 0.4, and 0.6 for oil–water two-phase flow experiments in a 3-inch pipe for different operating conditions. Two-phase inclinable flow loop has been employed for conducting the experiments for different fluid mixture flow rates and water cuts. The working fluids utilized are Exxsol mineral oil (D130) and potable water. The experiments were conducted for water cuts varying from 0 to 100% in steps of 20%, flow rates ranging from 2000 to 12000 barrels per day (BPD), and for horizontal and vertical flow loop inclinations (0◦ and 90◦). Liquid flow rates considered in the study match flow rates of real oil wells. The results indicate that the venturi pressure drop varies linearly with water cuts for both β ratios (0.4 and 0.6). The study indicates that the effect of inclination on venturi pressure drop is not appreciable for all water cuts and flow rates. Also, from the experimental results it can be concluded that venturi with β = 0.6 is favourable for multiphase flow metering (with flow rates ranging from 8000 to 12000 BPD). The tangible findings of the study will be helpful in combating multi-phase flow challenges in oil and petroleum industries.

1. Introduction

The multiphase flow is a complicated phenomenon which commonly occurs when two or more immiscible fluids such as water and oil flow through pipelines at the same time. Oil-water two-phase flows are frequently found in the oil, chemical, and petroleum sectors. Due to the deformable nature of fluids, the simultaneous flow of oil and water in a pipe represents a complex process. The complexity of oil-in-water flow creates a challenge to flow measurement. Since the transportation of

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crude oil with water lubrication can result in significant savings in pumping power, it is important to physically understand the characteristics of two-phase flow in pipes [1]. The flow rate (by mass or volume) of each phase in an oil-water two-phase flow is the process parameter that matters most. Measurement of process parameters is crucial for oil transportation and exploitation, particularly for the individual flow rates of water and oil.

In the oil industry, precisely measuring the flow of multi-phase flows is crucial. Accurate measurement of multi-phase flow behaviour is challenging, in contrast to single-phase flow measurements made with differential pressure meters [2]. Furthermore, the prevalence of multiphase flows in pipelines has spurred a great deal of research in this field.

The measurement of liquid flow rate in single-phase flows has been effectively accomplished by using venturi meters. If the flow pattern and operating conditions are carefully examined, the venturi meter device can also be employed for liquid flow rate measurement of oil-water flow applications. Multiphase flow is a frequent occurrence in venturi meters specifically in downhole and upstream pipelines. In the oilfield industry, using a venturi meter to measure pressure drop has become essential technology for production and management. The long, useful life of the meter body of a venturi meter is one its main benefits over other types of flow meters, which have relatively short life expectancies [3].

The measurement of pressure drop in upstream production wells (pipelines) and transportation pipelines is a challenging issue and needs a clear understanding. Presently experimental study has become a reliable approach to mitigate multiphase flow measurements. Pressure drop is the most important factor for determining the flow rates of each phase (oil and water) in pipelines. Substantial literature is available on the two-phase flow measurements of oil and water in pipelines.

Pal [4] investigated application of conventional orifice and venturi meter for monitoring the emulsions of two-phase (oil-water) flow. Empirical correlations of the discharge coefficients for different oil-in-water emulsions were developed based on experimental data.

The performance of hybrid flow meter system which consists of an oval gear flow meter and venturi meter for two-phase (oil-water) flow measurements was investigated by Li *et al.,* [5] for three horizontal pipes with 15mm, 25mm, and 40mm diameters. The measurement of oil-water two-phase flow in terms of total volume flow rate, total mass flow rate, and density has been found to be feasible.

Theoretical, numerical simulation and experimental testing of a two phase flow downhole flow model was conducted by Huang *et al.,* [6]. Flow patterns and pressure characteristics for different flow conditions were studied in venturi tube. They observed stratified flow pattern in the venturi tube. Air-water-oil multiphase flow experiments were conducted to measure pressure drop in 7 m long vertical pipe (internal diameter of 50 mm) loop by Silva *et al.,* [7]. Wet gas flow rate was measured by horizontal venturi meter (0.55 beta ratio) by Steven [8]. A new correlation was developed based on the measurements. Huang *et al.,* [9] investigated two-phase oil-air flow measurement by using venturi meter and void fraction meter. They proposed a new correlation to measure the flow rate. More recent research studies related to dispersion, flow and angle, pressure drop and angle, flow related parameters, phase-change, flow-pattern and void-fraction, oil-gas-water issues, drag resistance by pressure drop, etc are available in previous studies [10-16]. Basha *et al.,* [15] and Shaahid *et al.,* [16] on multiphase flows have focused attention on 4 inch diameter stainless loop/pipe. Flow rates were varied from 4,000 to 8,000 barrels-per-day (BPD).

Peixiang *et al.,* [17], Silva *et al.,* [18], Lide and Zhang [19], and Chun *et al.,* [20] have also carried out some experimental studies on venturi meters. However, a few studies were carried out on smaller diameter tubes and lower flow rates [17-20]. Also, our earlier paper on venturi meter focused on venturi pressure drop measurements of Exxsol mineral oil(D80)-water two-phase flow in horizontal and vertical 3 inch diameter (3 inch ID) pipe at different operating conditions flow [21].

In the wake of the above research studies, there is currently no work available in the literature on venturi pressure drop measurements of Exxsol mineral oil(D130)-water two-phase flow in horizontal and vertical 3 inch diameter (3 inch ID) pipe at different operating conditions. Literature also does not address explicitly the impact of venturi beta ratio (beta ratio of 0.4 and 0.6) on pressure drop for selected Exxsol mineral oil(D130)-water flow. Also, studies available in literature have not focused on the variables affecting the venturi pressure drop for oil-water flow rates ranging from 2000 BPD to 12000 BPD (simulating the actual flow rates in real oil wells). This is the motivation/thrust for the present experimental study and it focuses on the effect of flow rates, water-cuts, inclination angle, beta ratios, on pressure drop measurements of Exxsol mineral oil (D130)-water two-phase flow in 3 inch diameter inclinable flow loop. This is the novelty of the work and this work is one of its kinds. It is worth mentioning that "different fluids with different pipe sizes/orientations, with different operating conditions exhibit different flow characteristics".

This experimental study presents pressure drop measurements across venturi meters (of beta ratio of 0.4 and 0.6) for oil-water two-phase flow in a 3 inch diameter inclinable flow loop for different water cuts and fluid mixture flow rates. The Exxsol mineral oil(D130) and potable water have been used for the experiments. The experiments were conducted for flow rates ranging from 2000 to 12000 barrels-per-day (BPD), water cuts varying from 0 to 100% with a step of 20%, for two flow loop inclinations (0 and 90 degrees). The selected liquid flow rates (2000 BPD to 12000 BPD) match/simulate the actual flow rates in real oil wells. The tangible outcomes of the study will help in solving the pressure drop measurement problems encountered in petroleum industries.

2. Experimental Setup

The oil–water two-phase flow experiments were conducted to investigate the oil–water two-phase flow through venturi meters of β = 0.4 and 0.6. Figure 1 shows the multiphase flow loop test facility layout diagram. The flow loop mainly consists of 3 centrifugal variable speed pumps for water (WP) and 2 centrifugal variable speed pumps for oil, (OP) connected to a horizontal separator tank (WOST) with level indicators for oil and water, 3 inch stainless swing arm loop with venturi (beta ratio = 0.4 and 0.6), swing arm loop inclination can be varied from 0° - 90°. Oil and water flow rates are measured by turbine type flow meter (OFM, WFM), line pressure is measured by pressure transmitter (LPT), and pressure drop is measure by differential pressure transmitter. Details of the loop components are given in Table 1 and physical properties of D130 mineral oil is given in Table 2.

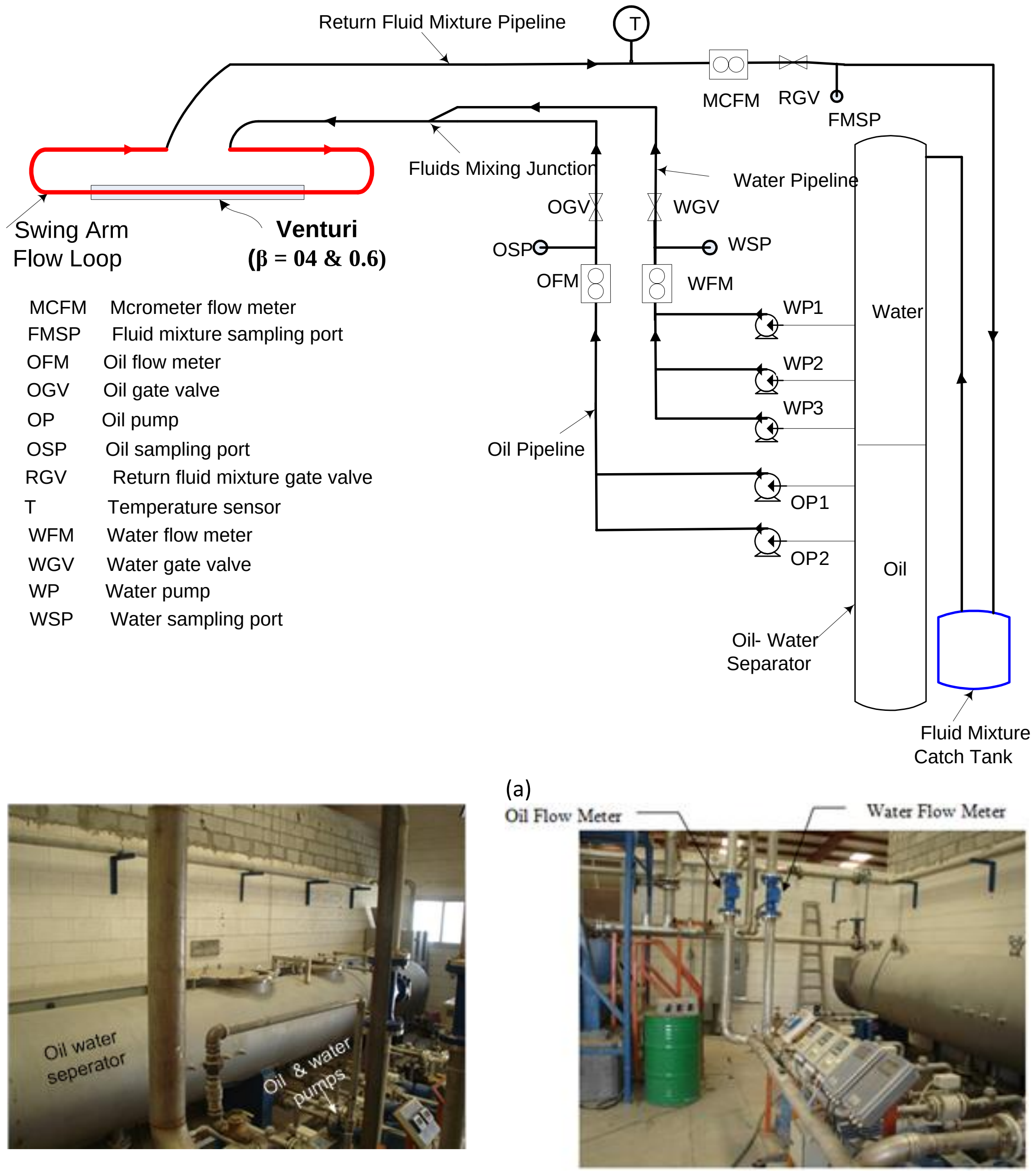

Fig. 1. (a) Multiphase flow loop test facility layout, (b) Pictures oil-water pumps and oil-water flow meters of the multiphase flow facility

Table 1
List of the equipment of oil–water flow experiments

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 meter	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%
DP2	ROSEMOUNT	300S2EAE5M9	0-12 inches of water column	±0.1%

Table 2
Physical properties of the mineral oil EXXSOL D130

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/m^3	ASTM D4052
Vapor Pressure (20.0°C)	< 0.0402	Inch H_2O	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

The multiphase flow experiments were conducted for each of the two venturi meters (β = 0.4 and 0.6) for different fluid mixture flow rates (2000-12000 BPD), water cuts (0-100% in steps of 20), and loop inclinations (0◦ and 90◦) as mentioned earlier. Experiments were conducted for oil-water multiphase (in 3inch pipe). Oil and water were pumped in the loop using centrifugal pumps. Required volume flow rate was attained by varying speed of pumps through variable speed drives. Turbine flow meters installed on the discharged line of the pumps were used for measuring the flow rates. Return gate valve (RGV, Figure 1) of the loop is throttled to set the required outlet pressure (e.g., 1 bar or 2 bars).

For a given flow rate, experiments were conducted, and pressure drop measurements were made across venturi as shown Figure 1. Once the steady state flow condition is achieved, differential pressure drops are recorded across venturi. CR 1000 data logger was used to record experimental data. Similar procedure was followed to measure pressure drop for other flow rates, water cuts, inclination and β ratio.

4. Results and Discussions

The experimental investigation was carried out to study the effect of water cuts, flow rates and flow loop inclinations (θ = 0◦ and 90◦) on venturi pressure drop measurements for the two venturi meters (β = 0.4 and 0.6). The working fluids were Exxsol mineral oil(D130) and Potable water for oil-water two-phase flow in a 3 inch diameter inclinable flow loop.

4.1 Effect of Fluid Mixture Flow and Water-Cut on Venturi Pressure Drop (for beta ratio β = 0.4) for Different Inclinations

The effect of water cut on venturi pressure drop for different flow rates are presented in Figure 2 and Figure 3 for horizontal and vertical flow loop inclinations for the two venturi meter (β = 0.4). It is clear from the results that the venturi pressure drop varies linearly with water cuts. This behavior more pronounced at higher flow rates. Similar behavior in venturi pressure drop is observed for flow rates ranging from 2000 to 6000 BPD and for the two inclinations considered. However, for any given water cut, venturi pressure drop is high for higher flow rates. As it can be noticed from Figure 2 and Figure 3 the effect inclination of venturi pressure drop is not appreciable for all water cuts and flow rates.

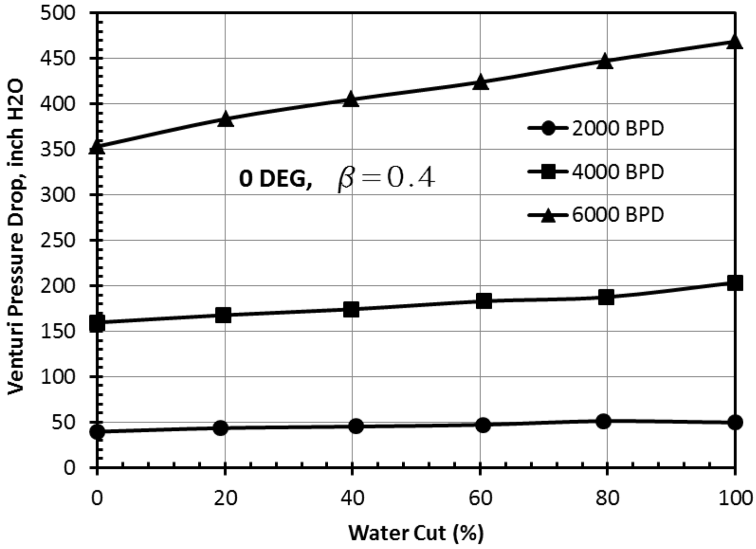

Fig. 2. Venturi pressure drop versus the water cut for different flow rates (β = 0.4, θ = 0°)

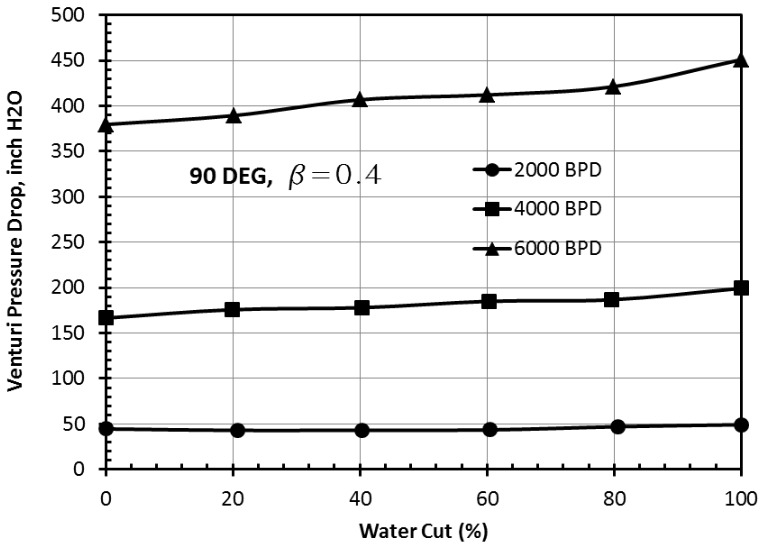

Fig. 3. Venturi pressure drop versus the water cut for different flow rates (β = 0.4, θ = 90°)

4.2 Effect of Fluid Mixture Flow and Water-Cut on Venturi Pressure Drop (for beta ratio β = 0.6) for Different Inclinations

The effect of water cut on venturi pressure drop for different flow rates are presented in Figure 4 and Figure 5 for horizontal and vertical flow loop inclinations for the two venturi meter (β = 0.6). It is can be seen from the figures that the venturi pressure drops increases linearly with water cuts for all flow rates (ranging from 8000 to 12000 BPD). Similar behavior in venturi pressure drop is observed for the two inclinations considered. For higher flow rate for any given water cut, venturi pressure drop has been found to be high. Again, as it can be noticed from Figure 4 and Figure 5 inclination has no effect on venturi pressure drop for all water cuts and flow rates.

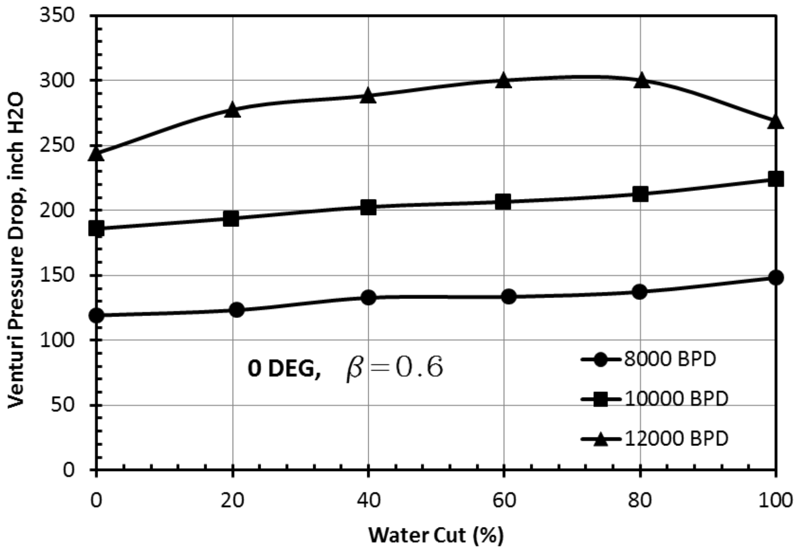

Fig. 4. Venturi pressure drop versus the water cut for different flow rates (β = 0.6, θ = 0°)

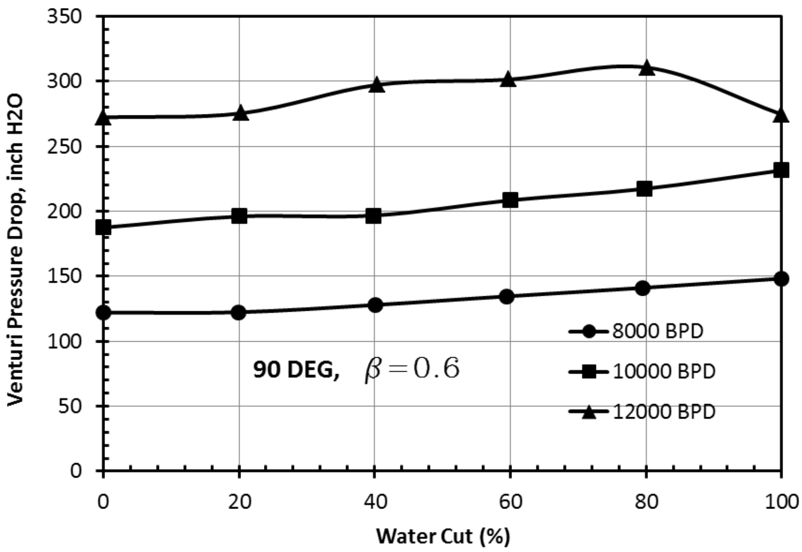

Fig. 5. Venturi pressure drop versus the water cut for different flow rates (β = 0.6, θ = 90°)

4.3 Effect of Venturi β Ratio on Pressure Drop for Different Water Cuts and Flow Rate

The effect of β ratio on venturi pressure drop for different water cuts and for different flow rates (6000 BPD for β = 0.4 and 8000 BPD for β 0.6) for horizontal and vertical flow loop inclinations is presented in Figure 6. It can be seen from the figure that the pressure drop is relatively higher for β = 0.4 for both inclinations as compared to pressure drop measured for β = 0.6 venturi. As pointed out earlier inclination has effect on venturi pressure drop. From the measured pressure drop data it can be concluded that venturi with β = 0.6 is favorable for multiphase flow metering (with flow rates ranging 8000 to 12000 BPD).

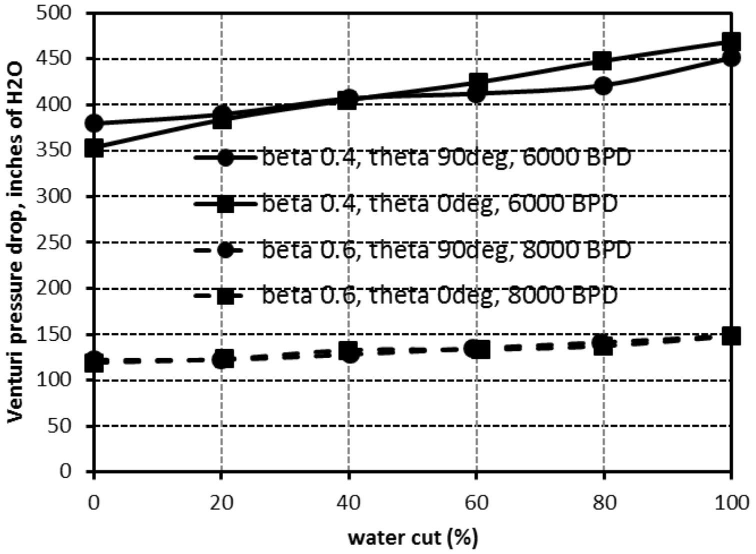

Fig. 6. Venturi pressure drop versus water cuts for different β ratios, inclinations and flow rates

5. Conclusions

The governing parameters of concern which affect pressure drop of two-phase oil-water flow across the venturi meter are water cut and angle of inclination. The study has investigated experimentally pressure drop measurements across venturi meters with beta ratios β = 0.4 and 0.6 for oil–water two-phase flow experiments in a 3-inch pipe. The experiments were conducted on a big-size, inclinable two-phase flow loop for different water cuts and fluid mixture flow rates. Potable water and Exxsol mineral oil (D130) were utilized for experimental work. The experiments were conducted for water cuts varying from 0 to 100% in steps of 20%, flow rates ranging from 2000 to 12000 BPD, and for horizontal and vertical flow loop inclinations (0◦ and 90◦). Experimental results indicate that the venturi pressure drop varies linearly with water cuts for both β ratios (0.4 and 0.6). The study indicates the effect of inclination on venturi pressure drop is not appreciable for all water cuts and flow rates. This is a very important conclusion which expands the applicability of venturi meters for all wells at all angles of inclinations. Also, from the experimental results it can be concluded that venturi with β = 0.6 is favorable for multiphase flow metering (with flow rates ranging 8000 to 12000 BPD. The selected liquid flow rates (2000 BPD to 12000 BPD) match/simulate the actual flow rates in real oil wells. The tangible findings of the study will be helpful in combating multi-phase flow challenges in oil and petroleum industries.

In our future research studies, attempt will be made to conduct study on physical properties (viscosity and density of oil-water), flow patterns, interface instability (R-T or K-H), or states (emulsification, cavitations, gas resistance), etc. This exercise will give a broader picture of the pressure drop measurements across venturi meters with beta ratios β = 0.4 and 0.6 for oil–water two-phase flow experiments in a 3-inch pipe.

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