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CFD Analysis of Two-Phase (Oil-Water) Flow in Horizontal Pipe

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ABSTRACT

In this paper, the behaviors of two-phase (oil-water) flow in horizontal pipe have been investigated numerically using ANSYS Fluent 16.1. For these simulations for oil-water stratified flow, Volume of Fluid (VOF) model and RNG k- ε turbulence model is adopted. A number of simulations have been carried out for different inlet velocity (0.5m/s, 1.0m/s, 1.5m/s, 2.0m/s, 2.5m/s and 3.0m/s) and for different volume fraction (*vf*) of oil (10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%). Numerical results demonstrate that pressure drop (ΔP) and wall shear stress (σ), both, are increasing with respect to inlet velocity and volume fraction of oil. A series of empirical relations were also developed to show the effect of inlet velocity and volume fraction of oil on the pressure drop and wall shear stress.

Keywords: CFD Simulation, VOF model, Two-phase flow, Oil-water, Pipe flow.

1. Introduction

Analysis of immiscible liquid-liquid two-phase flow in pipes has been a subject of intense research for several decades due to its fundamental significance as well as much related industrial application, especially in the petroleum and process industries. Though liquid-liquid flow systems play very significant roles in the petroleum and other industries, however very less attention has given as compared to the gas-liquid flow systems. Now-a-days, liquid-liquid flow systems have attracted more and more interest in the offshore oil industry. Typically immiscible liquid-liquid two-phase, i.e. oil-water, flow occurs in the co-current manner of in petroleum products transportation since oil and water are mostly produced at the same time. The transportation of crude oil is very important in the offshore facilities, where the oil is transported using pipelines to the processing facility.



Water flow

Figure 1.1: Oil Water two phase flow in horizontal pipe.

The water present in the crude oil significantly affects the transportation of petroleum oil from the well to an onshore platform [1]. The oil transportation pipes lie on

* Corresponding author. Tel.: +88-01761919895 E-mail addresses: abir.hasan.kuetme@gmail.com the seabed in either horizontal or inclined way. During the transportation process, the variation in water or oil volume fraction in the pipes can have a significant influence on pumping power required to pump the fluid, due to the change in the pressure drop across the pipeline. The presence of water in the pipe has a significant effect on the transportation of mixture of oil and water from the reservoir to the onshore or processing platform since the behavior of liquid twophase flow in tubes behaves differently from singlephase flow [2]. For variable mixture velocities and the water volume fraction, the fluid might have different flow regimes in the pipe, which might influence the input power requirement during the pumping of the mixture.

2. Literature Review

Lots of works have been carried on water and oil twophase flow in straight horizontal pipes in last two decades. Angeli et al. (1998) experimentally studied the pressure gradients for the co-current flow of low viscosity oil-water in horizontal pipes (D = 0.0254 m), made of stainless steel and acrylic resin, for different velocities and water volume fractions. It was found that at high Reynolds number, where dispersed flow patterns occur, there was a peak in pressure gradient during phase inversion and an apparent drag reduction affect when oil is the continuous phase [3]. Gao et al. (2003) numerically studied the pressure drop, liquid holdup, the axial velocity, and slippage, for the oil-water two-phase flow in the straight horizontal pipe and also verified with experimental data in the literature. Stratified water oil oil-water flow in a straight horizontal pipe is simulated numerically with VOF model. The simulation is done in a time-dependent way and the final solution which relates to steady-state flow is studied [4]. Elseth et al. (2001) experimentally study the behavior of flow of oil-water in the horizontal straight pipe (D =0.0508m). Pressure drops, slip ratio, velocity profiles, turbulence distributions and liquid holdup are measured for a various number of flow-conditions. A typical flow parameters measuring instrument laser Doppler anemometer (LDA) is used and applied as a transparent part of test pipe. Stratified and dispersed types of flow are observed [5]. Walvekar et al. (2009) have been studied volume phase fraction profiles and average insitu phase fraction on the 3D flow of liquid-liquid immiscible fluids in a horizontal pipe using computational fluid dynamics models. The unsteady state numerical simulations of liquid-liquid two-phase dispersed type flow in a pipe of inner diameter is equal to 0.0024 m have been done using commercial Computation fluid dynamics software FLUENT with the multiphase model. Oil-water system is selected as the two-phase system in this work. The k- ϵ viscosity model was implemented to explain the turbulence characteristics in the continuous phase [6]. Al-Wahaibi et al. (2012) pressure drop per unit length correlation for straight horizontal oil-water separated flow (stratified and dual continuous flows) was reported based on the experimental work of Angeli and Hewitt (1998). Zigrang and Sylvester friction factor correlation were changed and modified for oil-water multiphase flow. The pressure gradient equation was validated with the experimental pressure gradient results. This is the first pressure drop/gradient work that published for oilwater flow which includes a good range of working conditions, fluid properties, pipe diameters and materials. The proposed equation predicts the pressure drop per unit length with larger accuracy than the twofluid model [7].

3. Methodology

ANSYS Fluent 16.1 is used for these simulations, which is most widely used simulation software. For these simulations Volume of Fluid (VOF) model and RNG k- ϵ turbulence model is adopted. These simulations were conducted in 3-D. It was assumed for these simulations that temperature remains constant (means no Energy equation) and all physical properties also remain constant. The Navier-Stokes equations and the Continuity equation are the main governing equations.

The geometry has been created creating by ANSYS Design module, shown in Figure 1.1. The length of the pipe is 500mm and diameter is 40mm. For using volume fraction here used slice tool for parting the inlet region. Mesh generation have been done in Meshing Module. For mesh dependency test, different types of mesh have been created by changing element size from 2.5081e-004 meter to 5.0162e-002 meter. To create fine mesh near the wall. Inflation option is selected to smooth transition and transition ratio is 0.272. A maximum layer of inflation is 5. And growth rate is 1.2. For doing precision result face sizing and inflation were done in the inlet and outlet of the pipe. Maximum thickness for inflation is 2e-003 and element size for face sizing is taken 1e-003. Body sizing is also done in the whole pipe. After using all that features, number of nodes varies from 19684 to 190627.



Figure 3.1: Generated mesh in outlet and wall.

The properties water and oil are shown in Table 3.1.

Table 3.1: The properties water and oil.

Property	Water	Oil(Crude oil)
Density(kg/m ³)	998.2	780
Dynamic viscosity(Pa.s)	0.001003	0.00157
Interfacial tension(N/m)	0.17	0.17

Solver settings for these numerical analysis is listed in Table 3.2.

Table 3.2: Sc	lver setting	for these	numerical	analysis.
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Tuore etz. Sorver setting for these manierrear anarysis.				
Items	Inputs			
CFD Simulation	3-D Double precision			
Solver	Pressure-Based			
Time	Steady			
Gravity	9.81 m/s ²			
Modeling	Multiphase(VOF)			
Turbulence model	k-ε(2 equation)			
k-ε model	Standard			
Near-Wall Treatment	Standard Wall Function			
Material type	Oil, Water			
Turbulent Intensity	5%			
Turbulent Viscosity	10%			



Figure 3.2: Pressure drop vs number of element for 50%-50% oil-water at constant velocity of 1m/s.

A series of numerical simulations for different meshes with varying nodes have been conducted for the mesh independency test. Figure 3.2 depicts the variation of pressure drop (ΔP) for different mesh with different number of elements, which varies from 19684 to 190627. And here the two contours 158316 and 190627 are looks like same. It is clearly observed from figure that numerical results for meshes with nodes 158316 and 190627 have almost identical values. This indicates that mesh with 190627 nodes can generate more accurate result. As a result, following simulations were conducted with this mesh to confirm the numerical results are meshes independent.

4. Results and Discussion

4.1 Effect of velocity on pressure drop and wall shear stress



Figure 4.1: Pressure contour at outlet for 50%-50% oilwater two phase flow at different flow velocity.

Figure 4.1 depicts pressure contours at outlet for different inlet velocities (varies from 0.5m/s to 3.0m/s) at 50%-50% oil-water. It is observed that pressure intensity at outlet is increasing from lower velocity to higher velocity.



Figure 4.2 Variation of Pressure drop respect to velocity for 50%-50% oil water.

Figure 4.2 shows that the variations of pressure drop respect to inlet velocities. It is observed from Figure 4.2

that Pressure drop varies non-linearly respect to velocity, according to the following equation:

The value of R^2 , is equal to 0.9984, indicates that the numerical result follows a very approximation according to the equation (1).



Figure 4.3: The Wall shear stress variation respect velocity for 50%-50% oil water.

Figure 4.3 depicts that the wall shear stress variation respect to inlet velocities. It is observe from Figure 4.3 that wall shear stress increase non-linearly respect to velocity, which follows like as the following equation:

$$\sigma = 3.4942v^{1.4955}\dots\dots(2)$$

The value of R^2 is equal to 0.9976 also indicate very good curve fitting.

4.2 Effect of volume fraction on pressure drop and wall shear stress



Figure 4.4 Velocity contour at outlet for different volume fraction of oil constant flow velocity of 1m/s.

Figure 4.4 shows that the velocity contour at outlet for different volume fraction of oil like 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% for inlet velocity 1 m/s. It is observed from figure that maximum velocity region, indicate by red color, and translate from upper region to lower region by increasing volume fraction of oil.



Figure 4.5: Pressure drop vs Volume fraction of oil at velocity 1m/s.

In Figure 4.5, pressure drop is plotted for different volume fraction of oil. It is observed from the figure that pressure drop increase non-linearly with volume fraction of oil, like as the following equation

$$\Delta P = 0.0015vf^2 + 0.2396vf + 169.66\dots(3)$$

And the value of R^2 is 0.9962.



Figure 4.6: Wall shear stress vs Volume fraction of oil at velocity 1m/s.

In Figure 4.6, wall shear stress is plotted for different volume fraction of oil. It is observed from figure that wall shear stress increase linearly respect to volume fraction of oil. In here it is maintained a linear equation like

$$\sigma = 0.0048 vf + 3.0951 \dots (4)$$

And the value of R^2 is 0.9916.

5. Conclusion

In the present work oil-water two phase flow in horizontal pipe was numerically simulated using commercially software ANSYS Fluent 16.1. Numerical results shows that the pressure drop and wall shear stress, both, increase with respect to inlet velocity and volume fraction of oil.

NOMENCLATURE

- Pi : Inlet Pressure
- Po : Outlet Pressure
- ΔP : Pressure Drop
- σ : Wall shear Stress
- μ : Viscosity
- v : Velocity
- ρ : Density
- L : Length
- D : Diameter
- *vf* : Volume Fraction of Oil

REFERENCES

[1] Al-Yaari, Abu-Sharkh, F., 2005. CFD prediction of stratified oil-water flow in a horizontal pipe. Asian Trans. Eng. 1 (5), 155-162

[2] Beggs, H.D., Brill, J.P., 1973. A study of twophase flow in inclined pipes. J. of

Petroleum Technol. 607–617.

[3] Angeli, P., Hewitt, G.F., 1998. Pressure gradient in horizontal liquid–liquid flows. Int J.of Multiphase Flow 24(7), 1183–1203.

[4] Hui Gao, Han-Yang Gu, Lie-Jin Guo, 2003. Numerical study of stratified oil–water two-phase turbulent flow in a horizontal tube. Int. J. of Heat and Mass Transfer, 46, 749–754.

[5] Geir Elseth, 2001. An experimental study of oil / water flow in horizontal pipe. Doctoralthesis, Department of Technology (HiT-TF) Telemark University College Kjolnes Ring, N-3914 Porsgrunn Norway.

[6] Walvekar R, 2009. .Numerical study of dispersed oil–water turbulent flow in horizontal tube. J. of Petroleum Science and Eng. 65, 123–128

[7] Yusuf N., Al-Wahaibi Y., Al-Wahaibi T., Al-Ajmi, A.S. Olawale, I.A. Mohammed,

2012. Effect of oil viscosity on the flow structure and pressure gradient in horizontal oil–water flow. Chemical Engineering Research and design 90 1019–1030.