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Numerical Simulation of Two-phase Flow in U-bend Pipe

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Abstract

Kerosene oil-water flow via U-bend pipe is numerically modelled using CFD using the Eulerian model in this paper. The computational and experimental findings are in agreement. The investigation involves the analysis of the flow characteristics and pressure drop in a U-bend pipe for the transportation of oil and water. The study encompasses a range of superficial velocities, ranging from 0.2 m/s to 1.0 m/s. The U-bend geometry influenced the downstream pattern of flow. A rise in oil velocity revealed a core-annular flow pattern. At lesser oil-water velocities, a stratified flow profile was identified, while at higher oil-water velocities, a dispersed flow profile was established. It was observed that the pressure gradient exhibited a positive correlation with the increasing flow rates of both water and kerosene. The results suggest appropriate operating parameters for designing U-bend pipefitting.

Keywords

CFD, Core annular flow, Pressure drop, Flow pattern, U-bend pipe

Introduction

Due to the global depletion of light oil reserves and rising demand of energy leads to the emergence of dense crude oils as energy source. It is difficult to transport heavy oil due to its non-Newtonian properties. Dilution is one of the oldest and most popular ways for reducing heavy oil viscosity. When fluids are transported over long distances, the challenges associated with pressure loss become a greater concern. The addition of drag-reducing additives to heavy oil or the creation of core annular flow in transport pipelines reduce the pressure drop generated by friction in the pipeline. Water- lubricated heavy oil transport appeared to be one of the most promising options for dealing with the situation. In the lubricated pipe flow of heavy oils, a water annulus acts as a lubricant and separates the viscous oil from the pipe wall. The flow regime is known as annular core flow. Pressure loss is among the most significant parameter to consider while analyzing oil-water flow in petroleum sector. The inclusion of a less viscous water annulus encircling the oil core results in a significant decrease in the frictional pressure drop in this flow profile. Therefore the pressure drop values may decrease to levels that are nearly equivalent to those observed in single-phase water flow [1].

By utilising core CAF in the transportation of crude oil serves to reduce significant pressure drops caused by higher oil viscosity [2, 3]. In order to predict pressure loss and holdup via a straight pipe during core annular flow, Brauner developed a two-phase analytical model [4]. He also identified fluid viscosity ratio as the energy conservation factor. Liquid-liquid flows have gained less attention in contrast to the immense number of experimental works on liquid-gas

flow. Only a few investigations have been accomplished using liquid-liquid flow modelling in U-bend tubes. Russell et al. evaluated the oil-water mixture flow pattern through a straight pipe [5]. Water flow pattern was shown to be less affected by oil viscosity in an analysis of phase inversion by Arirachakaran et al. [6]. Lovick and Angeli experimented with a straight tube with the low-viscosity oil-water flow and observed that adding water to oil led to lesser pressure gradients than a single-phase oil flow [7]. Mukherjee et al. calculated loss in pressure and-holdup statistics for oil and water in an inclined pipe.They reported maximum pressure loss values near phase inversion [8]. In order to reduce pressure drop in oil pipelines use of nanoparticles and nanofluids for easier transport of crude oil by reducing viscosity [9] and wettability alteration [10] have recently evaluated.

Literatures show that various types of nanoparticles can improve crude oil transport through several mechanisms such as change in oil properties and reduced surface tension [11-14]. Addition of nanoparticles and nanomaterials properties of fluid like viscosity, density, specific heat, thermal conductivity change critically [15]. Ngan et al. [16] studied the effect of reducing interfacial tension on the phase inversion process by adding a small amount of glycerol in the water phase flow during horizontal pipe. It was found that reducing the interfacial tension causes an increase in the oil volume fraction to complete the inversion process. Parda et al. witnessed a significantly reduced pressure loss of 45 times in oil-water flow compared to single oil flow in a vertical tube [17]. Grassi et al. measured the similarity of experimental pressure reductions and fluid profile of oil-water in straight and slight bend pipelines by comparing pressure decreases [18]. Using a VOF model, Gao et al. used a straight tube to model oil-water phase. The pressure loss of pressure and slip ratio predictions were very close with the experimental results [19]. Pandey et al. [20] worked on water-kerosene oil flow through a horizontally dividing T-junction and found increasing kerosene and decreasing water surface velocity enhances water take off. Ooms et al. conducted CAF in a horizontal tube theoretically. Using theory of hydrodynamic lubrication, they predicted characteristics of interfacial waves [21]. Rodriguez et al. suggested two-fluid model-based transfer criteria for upward vertical and horizontal flow [22].

Effects of inclined angle on water hold up, slip ratio, and frictional pressure loss in straight and slightly bend pipes were investigated by Kumara et al. using a single-beam gamma densitometer [23]. Extensive numerical simulations were run to assess the pressure drop, volume fraction, and oil and water velocity pattern in a return bent conduit [24]. Hydrodynamic behavior of oil-water across a rectangular bend was observed using volume of fluid, standard k-ε and continuum surface stress models [25]. High-viscous oil-water flow behavior via U-bend was examined and discovered that the downstream phase distribution was greatly influenced by oil and water flow direction via bent, whereas the bent geometry had no effect [26]. The VOF model in combination with the continuum surface force model was employed to numerically simulate oil-water core annular flow via the returning bent [27]. It was discovered that geometrical characteristics affect overall pressure gradient and fouling incidence when the oil water passes via the return bent. The study focused on the annular movement of oil and water in various pipe geometries, and it was discovered that the energy-saving benefit of core-annular flow is affected by changes in pipe structure and oil characteristics [28]. U-bends are mostly found in pipefitting in petrochemical plants, power plants, refrigeration plants, and food industries. Very few works have been executed in a U-shaped conduit. Analysis of core annular flow in bent pipes is significant for designing and operating these pipes.

In the present study, numerical simulation has been performed using CFD tool to analyze the pressure drop and flow pattern for different variations of superficial velocities through a U-bend pipe. The results compared the flow profile of kerosene oil-water via a U-bent conduit in an experiment done by Sharma et al. [26]. These results may help design the heavy oil transportation pipeline system and suggest appropriate operating parameters for designing U-bend pipefitting.

Materials and Method

Table 1 exhibits the physical properties of kerosene oil and water which were used as testing liquids in the experiment. Sharma et al. validate kerosene oil-water flow modelling for pressure gradient and flow behavior in U-bend pipes [26]. Applied boundary conditions are mentioned in table 2.

The commercial CFD tool ANSYS fluent software was applied to resolve the governing equations based on the flow pattern of Kerosene-water. The Eulerian model-based volume of fluid approach was applied to predict pipes' oil-water flow dynamics. A pressure-based solver is used for dynamic and nonlinear dynamics, while a k-ε model is applied for turbulence. Geometry and grid were consolidated using ANSYS software.A 3D model has been generated to analyze U-bent core-annular movement. The flow pipe domain consists of downstream, upstream and U-bend. U-bend pipe has been created by connecting two long horizontal tubes (4 m long) having a diameter - 0.012 m, radius - 0.1 m, and curvature ratio of - 16.67 for the present work (Figure 1). The accuracy of the simulation is determined by meshing, which is one of the essential parts of the simulation. Themore cells formed on geometry, the more precise it would be. To improve the

Table 1: Physical characteristics of test liquids.

Experimental test liquid	Density (Kg/m³)	Viscosity (pa.s)	Interfacial tension (N/m)
Water	998.2	0.001	0.045
Kerosene	780	0.00115	0.045

Table 2: Applied boundary conditions.

Item	Boundary condition
Inlet	Kerosene superficial velocity, Usk = 0.4 m/s; Water superficial velocity, Usw = 0.2 m/s
Outlet	Outlet pressure (Atmospheric pressure, i.e., Patm = 101325 pa)
Pipe wall	Non-slip wall
Radius of curvature	(2R/D) =16.67

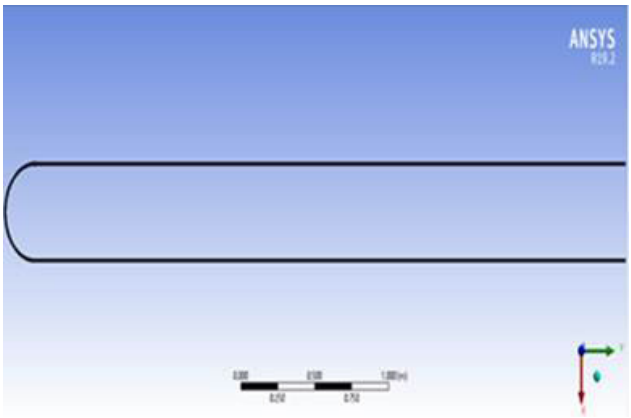


Figure1: U-bend geometry in ANSYS.

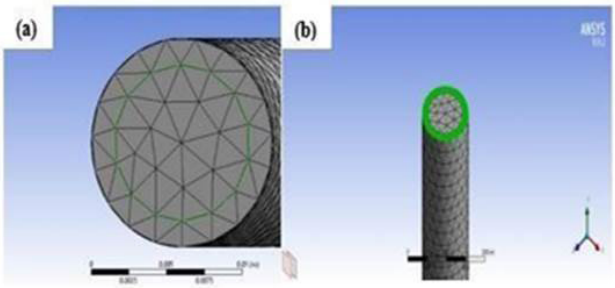


Figure 2: ANSYS meshing for circular pipe.

percentage of precision by forming tetrahedral cells, the cut cell form of meshing is used for simulation. A higher number of elements help more accurately predict kerosene-water flow behavior in return bend pipe. Therefore, a 3D grid was generated with 741405 tetrahedral elements for every 4 m long pipeline (Figure 2).

Results and Discussion

The simulation outcomes were assessed in relation to those of tests conducted on the movement of kerosene oil and water via a U-bent conduit by Sharma et al. [26], considering the specified boundary conditions. Oil-water flows of various patterns and velocities were observed in both cases.

Effect on flow patterns

A kerosene dispersed flow pattern was reported in bent and downstream sections at low water velocities. Different flow patterns have been observed in Kerosene and water at various velocities in bends, upstream, and downstream (Figure 3). U-bend geometry influenced the downstream flow pattern in both cases. Core-annular flow pattern found in high superficial velocity of oil. Plug flow reported at high water velocity in U-bend. Because of the smaller pipe sizes used in this study, the fouling angle and total pressure gradient are unaffected by flow direction via the return curve.

Effect of pressure gradient

A higher kerosene flow rate is required to achieve a given pressure gradient, while higher water flows have the same effect on the oil flow rate (Figure 4). Flow direction changes occur due tothe U-bend, resulting in a decrease in bend pressure

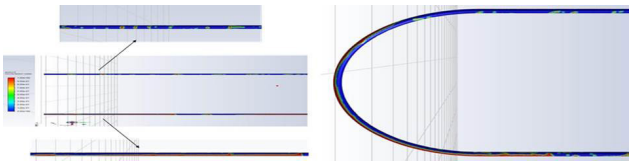


Figure 3: Volume fraction contour for inlet velocity (Usw = 0.6 m/s and Usk = 1 m/s).

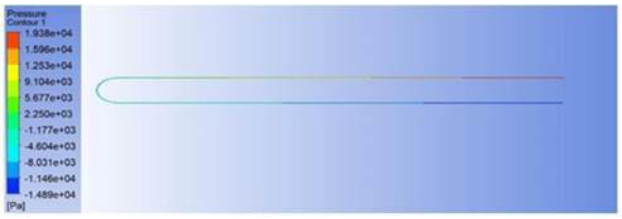


Figure 4: Volume fraction contour for inlet velocity (Usw = 0.6 m/s and Usk = 1 m/s).

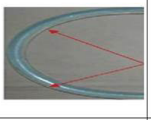
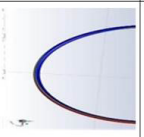
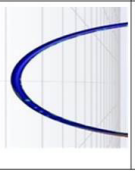
Experimental Observation (Sharma *et al.*(2011)	Numerical observation (Present study)	Flow Pattern	U_{sw}	U_{sk}
		Film inversion	0.45m/s	0.75m/ s
		Kerosene dispersed	0.6m/ s	0.15m/ s

Figure 5: Visualized flow patterns for different values of Usw and Usk.

in both situations (Figure 5). Pressure gradients increased at all test sites when superficial water velocity and oil fraction increased. The pressure gradient profile shifted as the flow system transitioned from oil-dominated to water-dominated. Results on pressure gradient showed a general reduction trend to a minimum as superficial water velocities rise. Velocity and pressure gradient at low mixture velocity were more significant at bend than upstream and downstream.

Conclusion

This study aims to investigate the flow of oil and water in an annular transport with a laminar core, via a return bent. FLUENT, CFD software was used to create a 3D model. The numerical approach was validated by calculating oil and water simulations' volume fraction and pressure contours, which correlate very well with experimental results. However, the prediction from CFD numerical simulation is not much like experimental results for pressure gradient, which is carried out by Sharma et al. [26]. The difference between numerical and experimental data is due to the model error, meshing, numerical error etc. Bend geometry influences the downstream flow regimes. A U-bend builds thick liquid water along its outer bend's walls and the start of the downstream tube. At low-ve-

locity values, gravitational settling is the dominant influence, while centrifugal force plays a more significant role at high-velocity values. The high difference in density of water and oil enhances phase separation due to buoyancy, allowing for high oil-water superficial velocities to the stratified flow zone. The superficial velocity and flow pattern of phases is directly associated to the difference in pressure gradients. The pressure gradient after the return bend was observed to be greater than at the bent and before the bent at increased water-oil velocities. It indicates that pressure drop decreased as the flow level increased downstream of the bend.

Acknowledgements

None.

Conflict of Interest

None.

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