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CFD MODELLING OF STRATIFIED OIL – WATER FLOW

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ABSTRACT

The development in field of advanced computing and software analysis tools for modelling the physical phenomenon has led researchers to use Computational Fluid Dynamics (CFD) for modelling of multiphase flows. CFD has become an essential industrial simulation tool for investigating an engineering system which includes design, analysis, fluid flow and performance determination for the system. Multiphase flow is encountered very frequently in flow through pipelines. Majority of oil fields produce both crude and gas and so multiphase flow is very common in petroleum industry. Stratified flow is a special case of multiphase flow in which a fluid of lower density flows over a fluid of higher density. This type of flow has an excellent potential application in reducing the pumping cost of crude transportation and so there is a scope for extensive research in this area. Stratified flow of oil-water system having a density ratio of 0.9 has been modeled in two-dimensional channels. A significant reduction in pressure drop required to pump a particular mass flow rate has been observed on using stratified multiphase flow when compared to single phase flow of oil. The simulations have been performed in a 2-dimensional control volume using ANSYS Fluent 14.5.

KEYWORDS: CFD, Multiphase flow, Stratified flow, Two-dimensional channel..

INTRODUCTION

Multiphase flow is encountered very frequently in flow through pipelines. Majority of oil fields produce both crude and gas and so multiphase flow is very common in petroleum industry. Stratified flow is a special case of multiphase flow in which a fluid of lower density flows over a fluid of higher density. The establishment of stratified flow based upon interaction of inertial, gravitational and surface tension forces and so it is established only under a set of particular combination of flow rates of oil-water. The flow is generally stratified under low velocity but as the flow rate is increased transition from stratified to non-stratified flow regime occurs .This type of flow has an excellent potential application in reducing the pumping cost of crude transportation and so there is a scope for extensive research in this area so as to understand this type of flow regime. Such type of flow is also encountered in nature in water bodies where stratification takes place due to the variation in temperature.

The two phase flow has been classified into several configurations which are (i) Bubble flow (ii) Plug flow (iii) Stratified smooth (iv) Stratified wavy (v) Slug flow (vi) Annular flow. The figure 1 below illustrates the various flow configurations in two phase flow:

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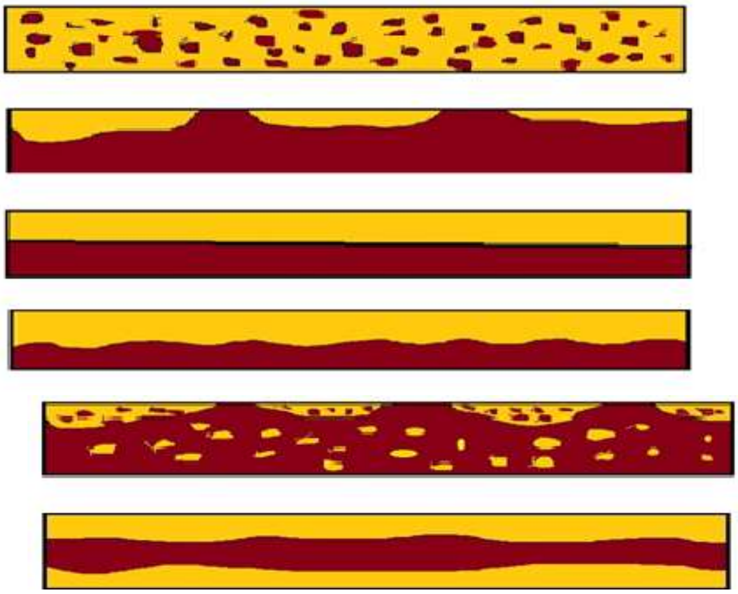

Types of flow configuration in two phase flow

LITERATURE REVIEW

Russel and Charles (1959) studied the effect of less viscous fluid in simultaneous flow of two immiscible liquids both under two layer and concentric flow conditions. They studied the flow of oil-water mixture through horizontal pipes and found three distinct flow patterns bubble, stratified and mixed. The research was focused mainly upon the input oil –water volume fraction. Charles et.al (1961) identified four different flow patterns in oil-water two phase flow through a horizontal pipe of diameter 2.5cm.they found the flow to be oil flowing as core in water, water droplets in oil, oil droplets in water and oil slug in water.

Transition from stratified to non-stratified horizontal oil-water flow have also been studied experimentally by (Al-Wahaibi et al. 2012) in a horizontal acrylic test section having ID 25.4 and 19 mm with water and oils of viscosity 6.4 and 12 centi poise as the test fluids .They have also studied effect of pipe diameter in transition from stratified to non-stratified flow and found that at particular superficial oil velocity ,the superficial water velocity for drop formation decreases as the pipe diameter increases . The same group also experimentally studied the flow pattern , pressure gradient in oil-water horizontal flow(Al-Wahaibi et al. 2014) in pipe of 25.4 mm ID and compared experimentally obtained pressure gradient with two fluid ,homogeneous and drift flux model and also found that pressure gradient is more for pipes of small diameter than compared to large diameter for same superficial oil-water velocity. They identified six flow patterns as stratified, annular, dual continuous, bubble, water in oil dispersion and oil in water dispersion. The effect of channel geometry on flow pattern and pressure drop has been studied by (Angeli and Hewitt 1998; Mandal et al 2007; Yusuf et al. 2012). Experimental study on pressure losses ,liquid holdup and flow patterns have been conducted by (Izwan Ismail et al. 2015) where they measured pressure drop and liquid holdup at different oil-water flow rates and observed strong effect of minimum flow rate on oil-water slippage. Experimental study of stratified–dispersed flow by using tracer method has been done by(Elseth 2001) in a pipe of diameter 80mm and length 50m with water-nitrogen mixture at 5 bar operating pressure. They measured tracer concentration, flow rate and circumferential distribution of film height, rate of droplet deposition and entrainment and the split of liquid between the wall layer and entrained droplets.Error analysis application of stratified momentum balance equation for determination of liquid wall shear stress and interfacial shear stress has been done by (Newton & Behnia 1998) in which they have applied error analysis based on the principle of maximum uncertainty on the governing equations. They conducted air-water experiments on pipes of diameter 50 and 80 mm and measured the pressure drop, liquid holdup and gas wall shear stress and compared with that predicted from the governing equations. They also observed that the performance of the stratified momentum balance equation is not significantly affected by uncertainty in the definition of mean liquid height even at low liquid holdup.

Studies of oil-water interphase and instability have also been carried out extensively using both experimental and analytical methodology. Interfacial waves in oil-water stratified flow have been studied (Castro & Rodriguez

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2015) in which they have collected data of wave amplitude , speed and wavelength and found them to be dependent on holdup ,pipe inclination ,density of liquid phases and interfacial tension. The wavy structure was found to impact on interfacial friction factor and consequently on pressure drop and the liquid holdup prediction. The friction factor for wavy stratified flow has been found to be several times more than the friction factor for stratified smooth flow and also it is observed that the interfacial friction factor increases as the amplitude of interfacial waves increases. Spectral density analysis of interface in oil-water stratified flow has been done by (Barral & Angeli 2014) and they have studied the structure of interfaces by estimating the power spectrum of interface signal and found that average power of spectrum increases with mixture velocity. They also found that at the transition to intermediate flow pattern there is a sudden increase in power values which is proportional to the interfacial friction factor for that flow pattern. X-ray tomography has been used by (Hu et al. 2014) to study flow structure and phase distribution in stratified flows. They studied the interfacial waves associated with the stratified flow and also proposed a co relation for predicting the fraction of gas bubble in the liquid layer.

MATERIALS AND METHODS

CFD Simulations:

The development in field of advanced computing and software analysis tools for modelling the physical phenomenon has led researchers to use Computational Fluid Dynamics (CFD) for modelling of multiphase flows. CFD has become an essential industrial simulation tool for investigating an engineering system which include design, analysis, fluid flow and performance determination for the system. A large body of literature is available on computational and numerical modelling of oil – water multiphase flow. Multiphase oil-water stratified horizontal flow has been numerically simulated by (Gao et al. 2003) in which they have solved only one momentum equation throughout the domain and have used RNG k-ε along with near wall low *Re* turbulence model for each phase while using continuum surface force approximation for calculating the surface tension. Results of pressure loss, local phase fraction profile, slip ratio and the axial velocity profile has been presented and experimentally verified by them and also they have presented the co-relations for oil holdup and pressure loss. Stratified two phase flow has been predicted by (Akai et al. 1981)where they have used a two equation model of turbulence and have predicted pressure drop, holdup and velocity profile. CFD simulations of horizontal oil-water stratified flow have been performed by (Zulhilmi et al. 2014) in a horizontal pipe of diameter 0.0254 m using Volume of Fluid (VOF) and RNG k-ε model for turbulence modeling. They used flow velocity of 0.2, 0.5, 0.8 and 1.1 m/sec while keeping the volume fraction of water 0.5 and have predicted the pressure at different flow velocities. They also found that as the velocity increases the pressure gradient also increases. CFD prediction of oil-water stratified flow in horizontal pipes by (Al-Yaari & Abu-Sharkh 2011) also simulates the stratified flow regime using VOF and RNG k-ε turbulence model. They have also investigated the phase separation for tested stratified flow points. De Sampaio et al. (2008) have used RANS (Reynolds averaged navier stokes) with the k-**ω** model for turbulence for modeling a fully developed two phase gas- liquid stratified horizontal flow using finite element method. CFD simulation of oil-water viscous flow through inclined upward flow and validation of interfacial morphology has been done by (Dasari et al. 2014) for a 5º upwards inclined pipe having a diameter of 0.0254 m and length of 7.2 m and have predicted five different flow patterns plug ,slug ,stratified wavy , mixed stratified and annular flow . CFD study of flow characteristic of two phase oil-water flow in horizontal pipelines has been done by (Desamala et al. 2014) in which they have used moderately viscous oil and water of viscosity ratio 107 and density ratio 0.89 as test fluids and successfully predicted slug ,stratified wavy ,stratified mixed and annular flow. They also found that in annular flow as the oil velocity is increased the total pressure of the mixture decreases.

The determination of friction factor is crucial for evaluating the shear stresses and use of CFD methodology in modeling of flow has made the determination of friction factors easier. The interfacial shear stress distribution is helpful in understanding interfacial heat and mass transfer behavior in two phase system and the local mass transfer may be influenced by the interfacial shear stress distribution .The co-relation for ratio of interfacial friction factor (f_i) and wall friction factor (f_w) has been developed by (Ghorai & Nigam 2006) for wavy stratified flow regime using CFD simulations and has been found to be good over certain range of Reynolds number. Interfacial friction factor for horizontal two-phase stratified flow have been determined by (Sidi-Ali & Gatignol 2010) and they have presented the expressions for gas-wall friction factor and the gas –liquid interface friction factor. The stratified flow in curved micro channels has been studied by (Picardo & Pushpavanam 2015) in which they have applied method of domain perturbation to obtain an analytical solution which is valid at low Reynolds number and when gravitational effects are dominated by the interfacial forces. They also calculated the critical Reynolds number for stability of stratified flow in curved micro channel for a curvature ratio of 0.2 and concluded that stratified flow is stable in a curved micro channel at low values of Reynolds number, curvature ratio, and the capillary number.

EXPERIMENTAL WORK

In this research work computational modeling of two phase oil-water stratified flow in a 2-dimensional horizontal channel has been done. The test fluids for this system are fuel oil of density 898 kg/m^3 and viscosity 0.927 **kg/m-s** and water having density 998.2 kg/m^3 and viscosity 0.00103 **kg/m-s**. Physical properties of above oil –water system have been listed below in Table (1).The oil water system under consideration is immiscible. The surface tension of the system is 0.02 Nm. Separate inlets are provided for oil and water and a separate common outlet is provided.

Physical property	Oil	Water
Density	898 kg/m^3	998.2 kg/m^3
Viscosity	0.927 kg/m-s	0.001003 kg/m-s
Specific heat	1880J/kg-k	4182 J/kg-k
Thermal conductivity	0.12 w/m-k	0.6 w/m-k

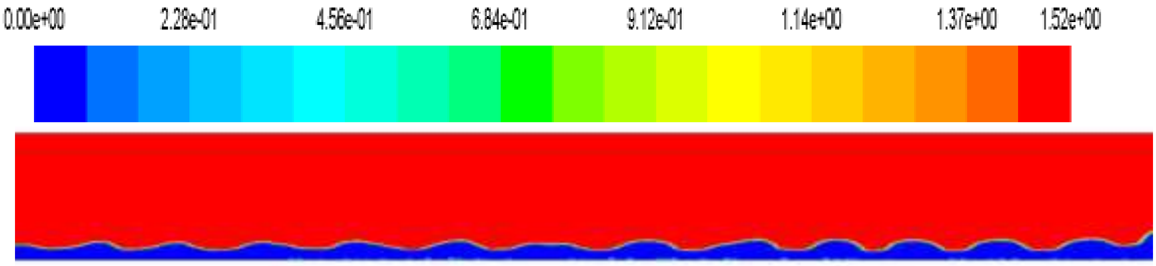
Physical properties of oil and water

RESULTS AND DISCUSSION

The simulations results helped to know the interface profile, velocity profile, pressure drop, temperature profile for non-isothermal case, wall shear stress and mass imbalance. The results of simulation for different cases are given below.

Case : For this case diameter is 26mm and the length of channel is 520mm and J_O =0.5m/sec; J_W=0.11m/sec

Contours of volume fraction



Contours of pressure

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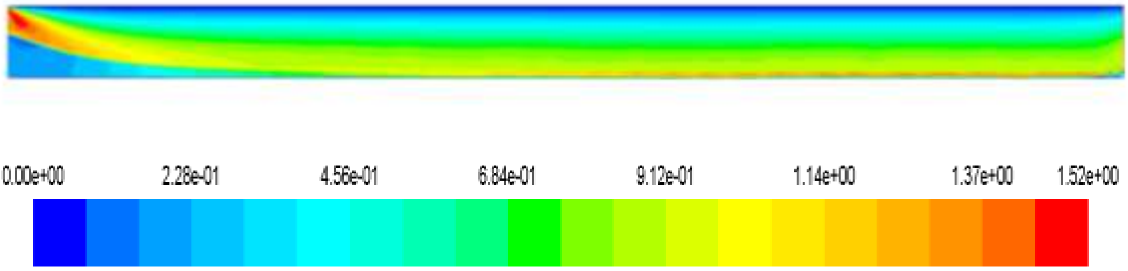
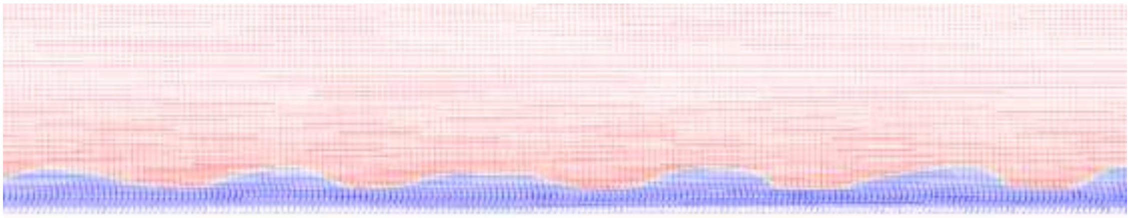


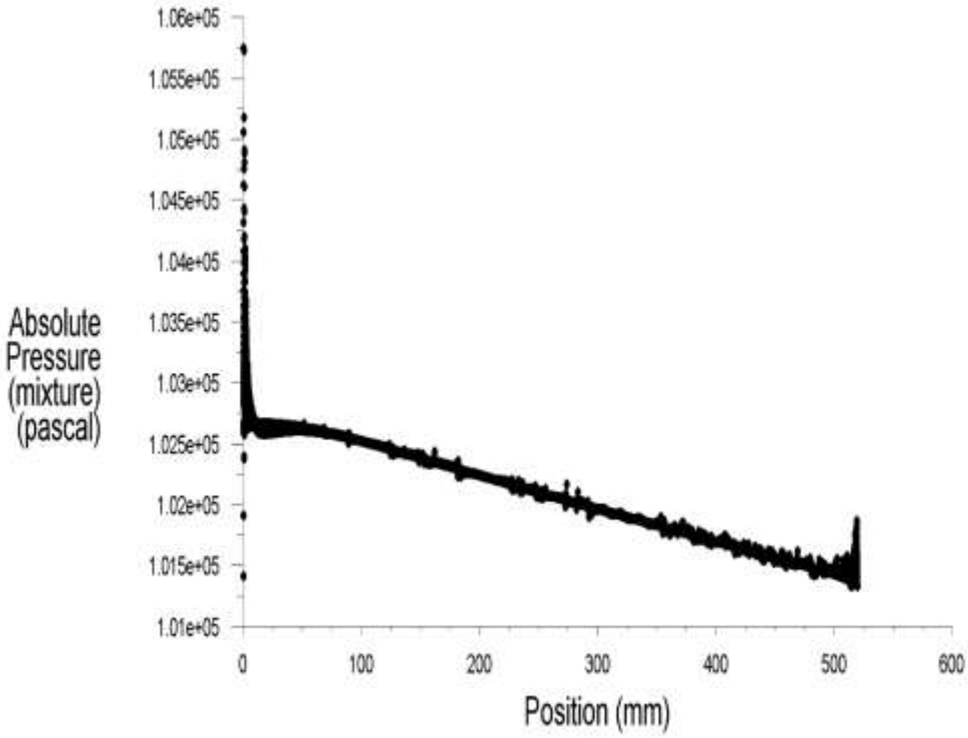
Contours of velocity

- The velocity vectors are given shown below

Velocity vectors



- The variation of pressure along the length is very important so as to calculate the pressure drop.



- The wall shear stress along the length is shown below

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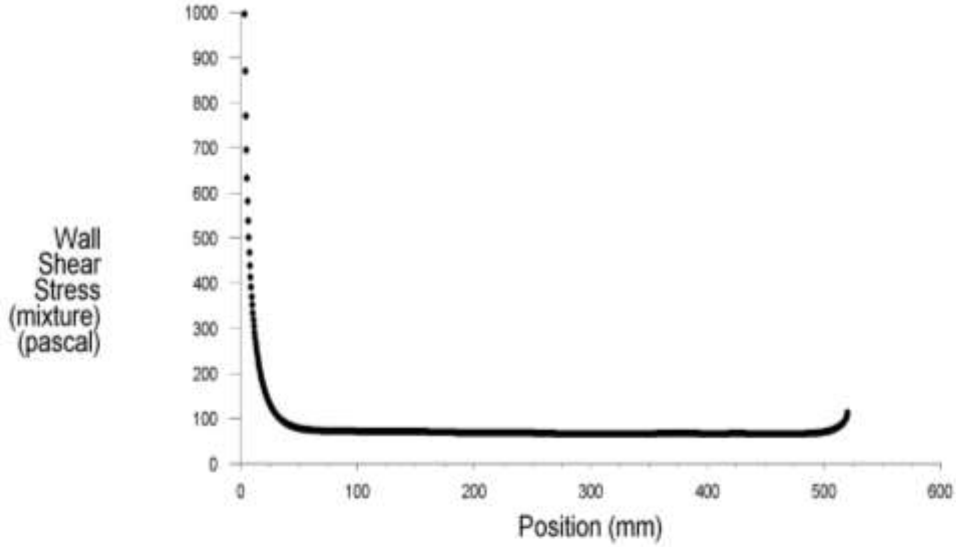
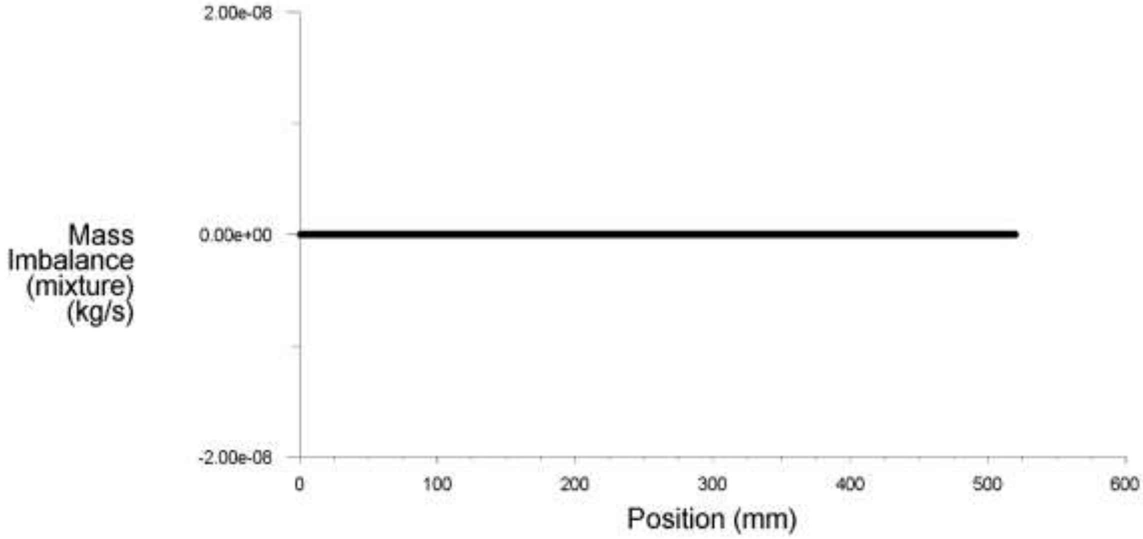


- To check continuity mass imbalance has to be know.



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