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# Investigation of Oil Water Flow in Wide Horizontal Pipes

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**Abstract**

Oil water flow in 6' pipeline is investigated at full scale using CFD application OLGA. The effect of flow rate, water cut, and temperature on the pressure gradient is investigated by manipulating different values at different flow rated. Results are presented and analyzed.

***Keywords:*** *Oil water, wide pipe, horizontal, pressure gradient.*

## 1. Introduction

Simultaneous flow of two immiscible liquids is commonly encountered in different industries such as food and refrigeration industries as well as in nature. In petroleum industry, oil and water are usually produced together and required to be transported from the wells to the production facilities and the market. Understanding of the characteristics of the oil water flow in pipes is vital for smooth and cost effective operations of petroleum pipeline by optimizing the pumping power requirements
[1] and [2]

Unlike the liquid gas two phase flow, the oil water (liquid- liquid two phase flow) is actually affected by the variation in viscosities and the emulsion formed at the interface. Moreover, the oil rheological behavior may vary [2] which make it more complicated to study. Moreover, the flow patterns the flow take is also influencing the pressure gradient [1] [2] [3]

Different attempts were made to study the oil water flow in horizontal pipes from different aspects such as work of [2][3] and Mohammed [4] who conducted experimental and computational work to investigate the flow patterns and observed SW, SWD, SMW, SMO and three layers of flow and dispersed flow pattern.

Pressure drop along the oil water pipeline is of special interest for many researchers who tried to investigate how it is caused. Wei Wang et al [2], claimed that the impact of gravity viscosity and interfacial tension in the stabilization of oil water separated flow is significant. Moreover, the impact of shear stress in viscous oils is very clear and can be characterized by ignoring the velocity of the viscous phase (oil).the same has been studied in the flow through narrow pipes and pressure gradient is found to be quite higher compared to that of single phase flow W. Adrugi et al [6]

Other worker studied the effect of viscosity [3] [4] [5], however viscosity can be reduced by different means such as mixing with industrial solvents or increasing the temperature as [4]

Most these works have covered the flow in relatively narrow pipes and limited test sections length. Recent developments in CFD make it possible to widen the ranges of the analysis. Some workers have used different CFD tools for analysis of oil water floe in horizontal pipes from different aspects such as [4] [5].

Current work utilized the enhanced capacity of the CFD to investigate the oil water flow in horizontal pipes at full scale with focus on the pressure losses. Actual reading from an oil field in Sudan is used to build and validate the model. Then different parameters were manipulated and obtained results are discussed.

## 2. Mathematical Model

The fluid flow is governed by continuity equation, momentum equation and the energy equation. The balance equations contains the interaction terms to incorporate the transfer of mass, momentum and energy from interface the phases which made it more complicated than the single phase model.

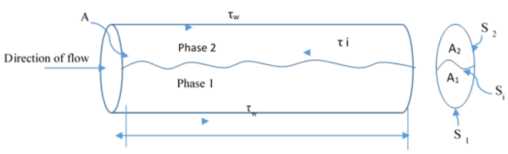


**Figure 1: Unit flow control volume**

Continuity equation

With reference to fig (1) above, equation of mixture motion can derived as follows:

For phase 1:

$$\frac{\partial}{\partial t}\left(\rho_1(1-\propto)\right)+\nabla.\left(\rho_1(1-\propto)u_1\right)=S_{12}+S_1 \text{ --- (1)}$$

Phase 2:

$$\frac{\partial}{\partial t}(\rho_2 \propto)+\nabla.(\rho_2 \propto u_2)=-S_{12}+S_1 \text{ ---- (2)}$$

Where $S_1$ represent external source of matter enters the system and $S_{12}$ is source term represents rate of change per unit volume.

For steady state flow of incompressible fluids with no phase changes these will reduces to

$$\frac{\partial}{\partial t}(1-\propto)+\nabla.\left((1-\propto)u_1\right)=0 \text{ --- (3)}$$

And $$\frac{\partial \propto}{\partial t}+\nabla.(\propto u_2)=0 \text{ --- (4)}$$

Momentum balance equation:

Rate of change of momentum = rate of momentum outflow – rate of momentum inflow – rate of momentum accumulation = net forces acting on the control volume.

$(W_1 u_1+\partial/\partial z\,(W_1 u_1)\,\delta z)\ W_1 u_1+\ \partial/\partial t(u_1 \rho_1 (1-\propto)A\,\delta z)$ --- (5)

Where $W_1=\rho_1(1-\propto)A$, and thus net rate of momentum change for phase 1 becomes:

$$\delta z\left(\frac{\partial}{\partial z}u_1^2\rho_1(1-\propto)A\right)+\frac{\partial}{\partial t}(u_1\rho_1(1-\propto)A) \text{ ---- (6)}$$

Force acting on the control volume for phase 1:

$$P(1-\propto)A-P(1-\propto)A+\frac{\partial}{\partial z}(P(1-\propto)A\delta z)-(P\delta z\frac{\partial}{\partial z}((1-\propto)A)-\tau_{w1}\delta z S_1+\tau_{wi}\delta z S_i \text{ ---- (7)}$$

Equating momentum rate of change and net forces acting on phase 1 resulted in:

$$-(1-\propto)\frac{\partial P}{\partial z}-\frac{\tau_{w1}S_1}{A}+\frac{\tau_i S_i}{A}=\frac{\partial}{\partial t}\left(u_1\rho_1(1-\propto)\right)+\frac{1}{A}\frac{\partial}{\partial z}(W_1 u_1) \text{ ---- (8)}$$

Similarly for phase 2

$$-\propto\frac{\partial P}{\partial z}-\frac{\tau_{w1}\rho_1}{A}-\frac{\tau_{w2}\rho_2}{A}=\frac{\partial}{\partial t}(\rho_2\ u_2\ \propto)+\frac{1}{A}\frac{\partial}{\partial z}(W_2 u_2) \text{ ---- (9)}$$

Adding the two equation under the steady state condition yields the mixture momentum equation as:

$$-\frac{\partial P}{\partial z}=\left(\frac{\tau_{w1}S_1}{A}+\frac{\tau_{w2}S_2}{A}\right)+\frac{1}{A}\frac{\partial}{\partial z}(W_1 u_1+(W_2 u_2)\ ) \text{ -- (10)}$$

## 3. Computational work and results

The commercial software OLGA is used to simulate the different operation cases and to predict the necessary parameters. Pipeline specifications as stated below are fed to the software and orientation is considered horizontal

**Table 1: Pipeline specifications**

| SN | Outer diameter [m] | 0.1524 |
|---|---|---|
| 1 | Internal diameter [m] | 0.1366 |
| 2 | Pipeline Length [m] | 50 000 |
| 3 | Roughness [mm] | 0.125 |
| 4 | Buried Depth(m) | 1.2 |

Further the crude oil specification fed to the software are as follows:

**Table 2: Oil properties**

| SN | Property | Value |
|---|---|---|
| 1 | API Gravity @ 60 °F (15.6 °C) | 23.87 |
| 2 | S. G. → Relative Density g/cm³ @ 60 °F (15.6 °C) | 0.9107 |
| 3 | Relative Density g/cm³ @ 60 °F (15.6 °C) | 0.9099 |
| 4 | Water cut | Varying |

Three different flow rates are considered for the simulation to represent the low flow rate at 1200 BLPD and medium rate at 4000 BLPD and high flow rate at 6000 BLPD.
Water cuts at 0, 20, 40, 60, and 80 % are used to reflect the impact of the dilution on the pressure gradient. Moreover the temperature profile is obtained along the pipeline at different concentration to reflect the viscosity impact as the viscosity if a function of the temperature.

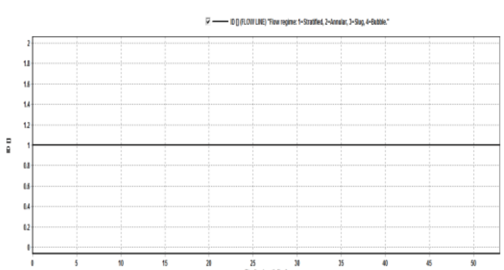

**Figure 2: flow regime along the pipeline at 1200 BLPD**

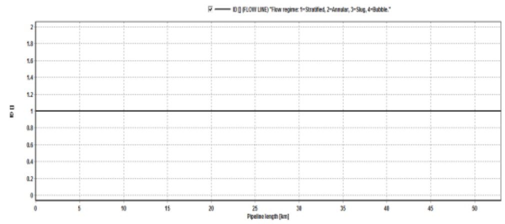

**Figure 3: flow regime along the pipeline at 4000 BLPD**

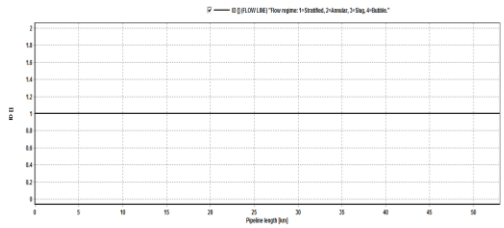

**Figure 4: flow regime along the pipeline at 6000 BLPD**

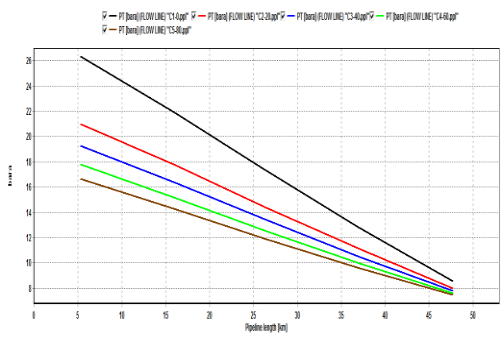

**Figure 5: pressure drop along the pipeline at different water cuts and flow rate of 1200 BLPD**

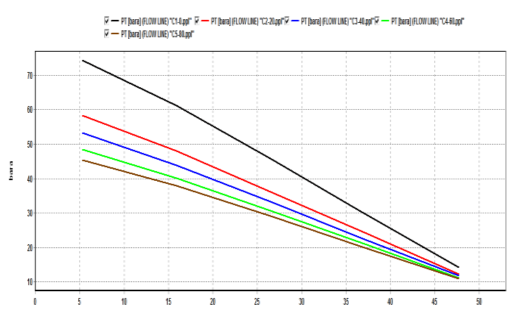

**Figure 6: pressure drop along the pipeline at different water cuts and flow rate of 4000 BLPD**

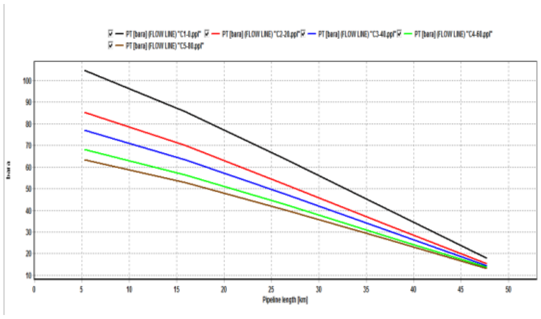

**Figure 7: pressure drop along the pipeline at different water cuts and flow rate of 6000 BLPD**

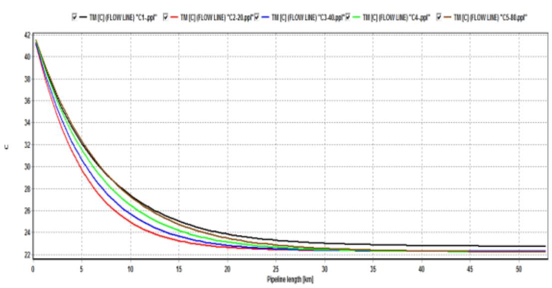

**Figure 8: Temperature profile along the pipeline at different water cuts and flow rate 1200 BLPD**

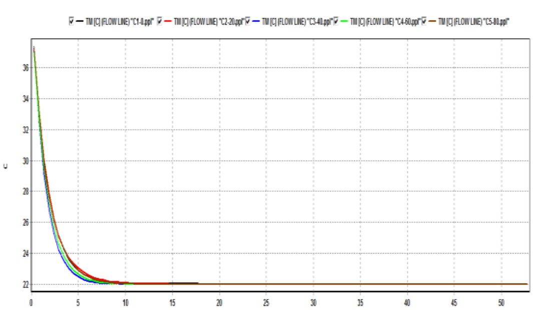

**Figure 9: Temperature profile along the pipeline at different water cuts and flow rate 4000 BLPD**

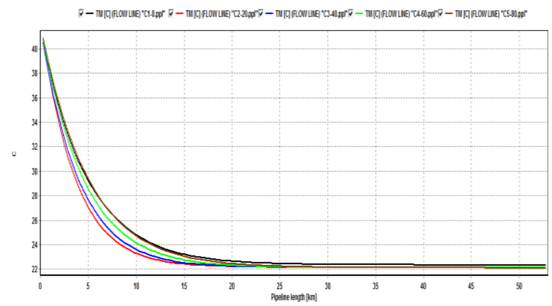

**Figure 10: Temperature profile along the pipeline at different water cuts and flow rate 6000 BLPD**

## 4. Discussion

It is clear that the flow is separated all through the pipeline regardless the flow rate or the water cut as can be seen from figures 2, 3 and 4 This is basically because of the basic assumption of horizontal orientation of the pipeline and the difference in the densities as well as the absence of gas flow or accelerations. Thus oil and water tends to segregate and stratified flow pattern will prevail.

Pressure gradient is found to be extremely higher when oil is flowing solely when compared to oil water flow at any concentration as shown in fig (5). Nevertheless, increase of water cut in the mixture is mobility and hence reduce the pressure gradient. This observation is valid for all the three flow rates scenario examined in this work and illustrated in fig (6) and (7). Addition of water will dilute the mixture and reduces the viscosity. Thus the more water cut, the less mixture viscosity and hence the less pressure decline encountered.

It can also be noted that pressure gradient is increasing proportionally with the flow rate increase within investigated flow rates.

Mixture concentration (water cut) as concluded from Fig (6), (7) and (8) is found to have minor effect on temperature profile, however the profile will slightly improved with water cut increase. But it is better improved with reduced flow rates.

## 5. Conclusions

The oil water flow in horizontal wide pipes can be significantly improved by increasing the water content in the mixture

## 6. Acknowledgment

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**Nomenclatures**
A: Cross sectional area of pipe
$A_1$, A2: Cross sectional area of pipe filled by phase 1 and 2 respectively.
SW: stratified wavy flow
SWD: stratified wavy drops
SMW: stratified mixed water layer
SMO : stratified mixed oil layer
BLPD: barrel liquid per day
$W_1$, $W_2$ rate of momentum change of phase 1 and 2 respectively.

**Greek Symbols**
μ: Viscosity, Pa.s
ρ: Fluid density kg/m3
$\tau_{xy::}$ shear stress, Pa
α: liquid holdup

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