SIMULATION OF OIL – WATER INTERACTION AT DOWNHOLE

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CERTIFICATION OF APPROVAL

SIMULATION OF OIL – WATER INTERACTION AT DOWNHOLE

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Muntaqim Shah Pereira

ABSTRACT

This project will be focused on simulating two-phase flow of water and oil in a down hole. The simulation will be an attempt to model the interaction of the two fluids in a natural environment where reservoir pressure in the sole driving force.

This paper will be divided into five parts which are introduction, literature review, methodology, results and discussion, and conclusion and recommendation. Introduction will be a background study on the title and will also touch on the problem statement, scope of work and feasibility of the project. Literature review will touch on the research done on the project that will be used as reference and the software's that will be used during the simulation. Methodology will be talking about the flow of work, milestones that are key in the project and also list of software used during the simulation. Results and discussion will discuss the results obtained from the simulation. Conclusion and recommendation will be the summary of what has been concluded so far and also some recommendations for the project.

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CHAPTER 1: PROJECT BACKGROUND

1.1 BACKGROUND STUDIES

Oil, or petroleum, was first used in mass amount during World War II by America, which later made them one of the world super powers. As a fossil fuel, petroleum is made from dead organisms that were buried under the sedimentary rocks and later exposed intense pressure and heat. The whole process of conversion from dead organisms to fossil fuel takes thousands of years, just like how natural coal is formed, except natural coal is made from wood and not buried as deep as petroleum.

One of the most common ways to extract petroleum from deep beneath the surface is by drilling. A well is dug out, walls cemented and cased before a device is lowered down and exploded in order to perforate the bottom of the well, which allows the oil into the casing. Then a pipeline is constructed to export the oil collecting at the bottom of the well to the surface where oil is stored and shipped.

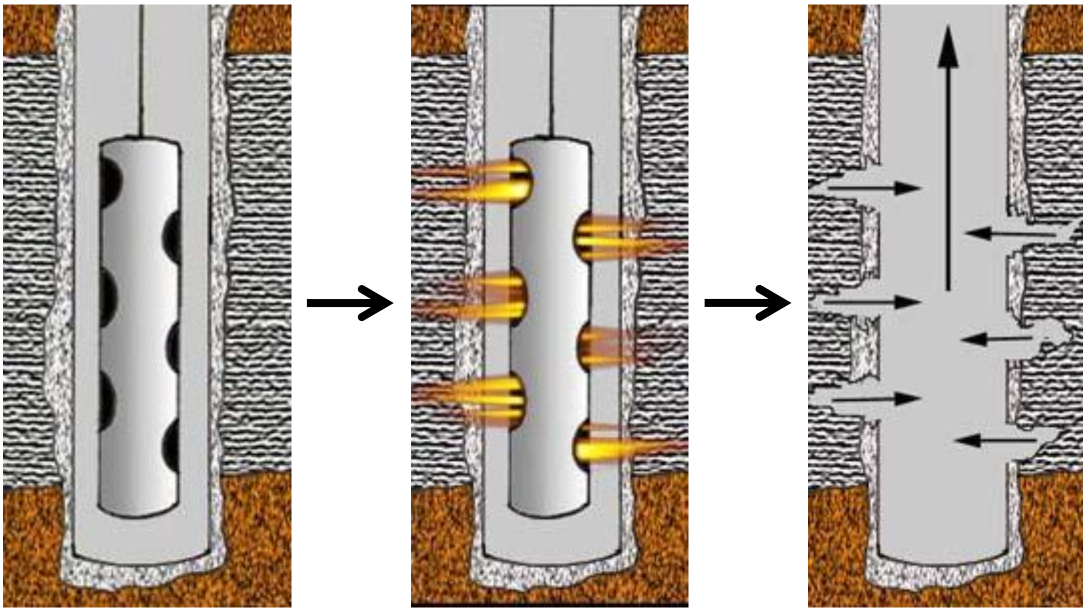


Figure 1.1 Perforation process of oil well [1]

In an oil bearing formation, it is always natural to have water underlying it. The formations will normally have a porous medium, normally sand, that allow both fluids to flow. Since oil is less dense than water, the water acts as the natural pump for the oil, pushing it upwards which causes it to enter the perforations and also help to push the oil upwards. The whole process is just a perfect system as minimum maintenance in needed since it is all natural processes and not much energy is needed to perform the additional tasks.

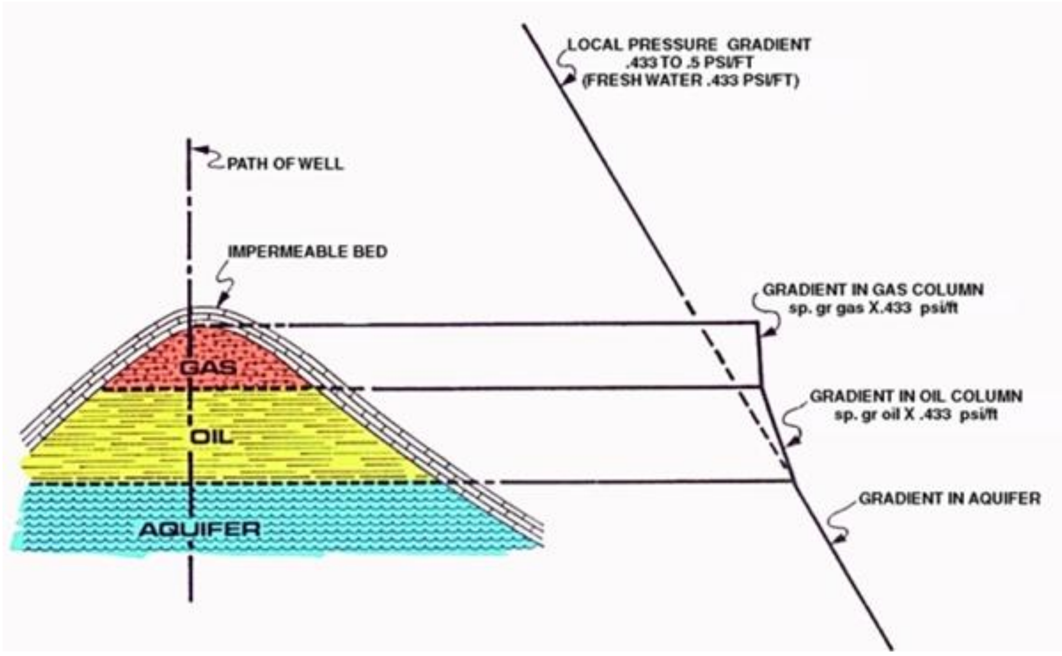


Figure 1.2 Oil bearing formation [2]

1.2 PROBLEM STATEMENT

Both oil and water have their own role in the stabilization of the fluid flow during production at a platform. As water starts to dominate the flow, the production value decrease, meaning cost of oil and water separation will be higher till at the end, producing oil will bring loss to the company. As a measure to reduce this loss, the simulation is done.

1.3 OBJECTIVES AND SCOPE OF STUDY

The objectives of the project are:

a) To simulate the phenomenon in order to further understand the nature of the 2-phase flow of oil and water.
b) To analyse the results obtained from the simulation.
c) To produce an academic paper to be submitted to a conference.

1.4 RELEVENCY OF THE PROJECT

With regards to production of oil in general, the project has little relevance. But, for the study of the flow of oil and water in a natural environment, and the designing of a separation device at downhole, the project provides more understanding on the flow characteristics of the fluids, making the designing process easier and targeted area known.

1.5 FEASIBILITY OF THE PROJECT

Within the given time frame, it is feasible to complete the project while maintaining a consistency throughout the project.

During the first part of the project (FYP I), the scope of work for the project will be:

a) Familiarization with the software that will be used during the simulation process.
b) Research on the flow characteristics of the fluids and the models to be used for the simulation.
c) Progress reporting to supervisor to ensure still on the right track.

During the second part (FYP II), the scope of work will be:

a) Performing the simulation of the project.
b) Improving and analysing the simulation.
c) Preparing the academic paper.

CHAPTER 2: LITERATURE REVIEW

For the project, the literature review will be focusing on the flow characteristics that are describe in papers and journals. A review of the software's being used will also be done to increase the understanding of the tools behind the simulation.

2.1 Flow Characteristics

In a naturally driven drive mechanism, two elements are there to provide 'push' to the oil, namely the gas cap, and also the water. As the water below pushes the oil upwards into the perforations, the gas cap pushes down the oil. Water drive can be used to produce 50% or more of the oil, while oil caps help recover around 20% - 40%.

From the literature studied, we can see that there is two main group of flow pattern, oil-dominated and water-dominated. From studies by Flores et al.[6], we can see that the water-dominated flow has a high slippage, which leads to a low frictional pressure gradient, while oil-dominated flow has a negligible slippage, which leads to high frictional pressure gradient. This shows that a water-dominated flow has a higher flow rate than an oil-dominated flow.

2.2 Software Used

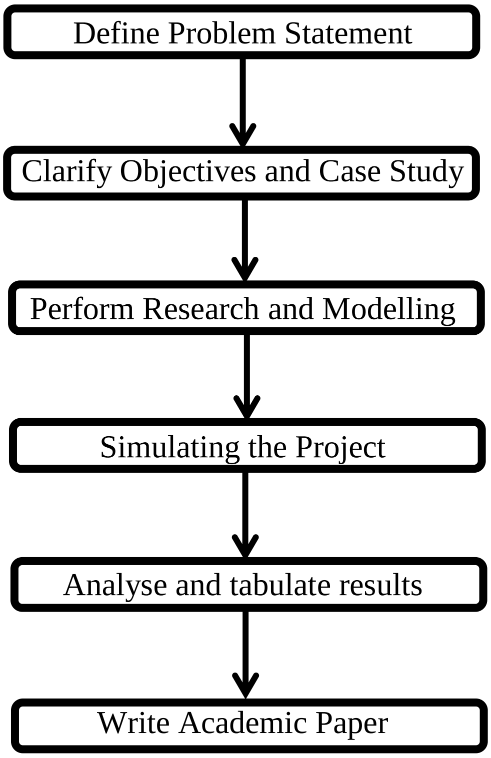
For the modelling of the downhole, Solid Works was used. Solid works is an easy-to-use yet powerful modelling software that can be used to model most of the things to do with engineering. It is also the software being used the most before, thus knowledge on what can be done is present. The meshing of the model is now done in Ansys, so the no use for any other meshing software to be used.

Fluent will then be used to simulate the flow of fluids in the meshed model. Fluent is software under ANSYS, which focuses on CFD computations and simulations. Fluent can be used to simulate laminar and turbulent flow, transport phenomena such as heat transfer and chemical reactions, and most importantly, flow through porous media. In any oil well, the oil-water-gas mixture will always be in a porous media such as sand. Fluent can also simulate multiphase flow, in our case oil and water.

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

The sources of research are from books and technical papers. UTP IRC has become the main location to provide main source of research for books. As in any project or research, certain methods are adopted in order to complete it. For the project, the method adopted is as following:



3.2 Project Activities

During the project, several activities need to be done in order to finish the project.

a) Research by referring to materials found in the internet and also from UTP IRC.
b) Study the software's that will be used to solve the simulation processes.
c) Testing and simulating the project using software's studied previously.
d) Analysing, interpreting and documenting the simulation results.
e) Collecting all data to be documented during academic paper construction.

3.3 Key Milestone / Gantt Chart

No.	Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project topic selection.														
2	Preliminary research work.														
3	Extended Proposal defense Submission.														
4	Proposal Defense.														
5	Testing of simulation software														
6	Data Collecting and Modelling														
7	Interim draft report submission.														
8	Interim report submission.														

Figure 3.1 FYP I Gantt chart

No.	Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Simulation of project															
2	Improvement process															
3	Analysis of result															
4	Progress report submission															
5	Provide simulation discussion and conclusion															
6	Prepare final report															
7	Pre - EDX															
8	Draft report submission															
9	Dissertation submission															
10	Technical paper submission															
11	Oral Presentation															
12	Project Dissertation submission															

Figure 3.2 FYP II Gantt chart

- Key milestone   - Process

3.4 Tools and Software

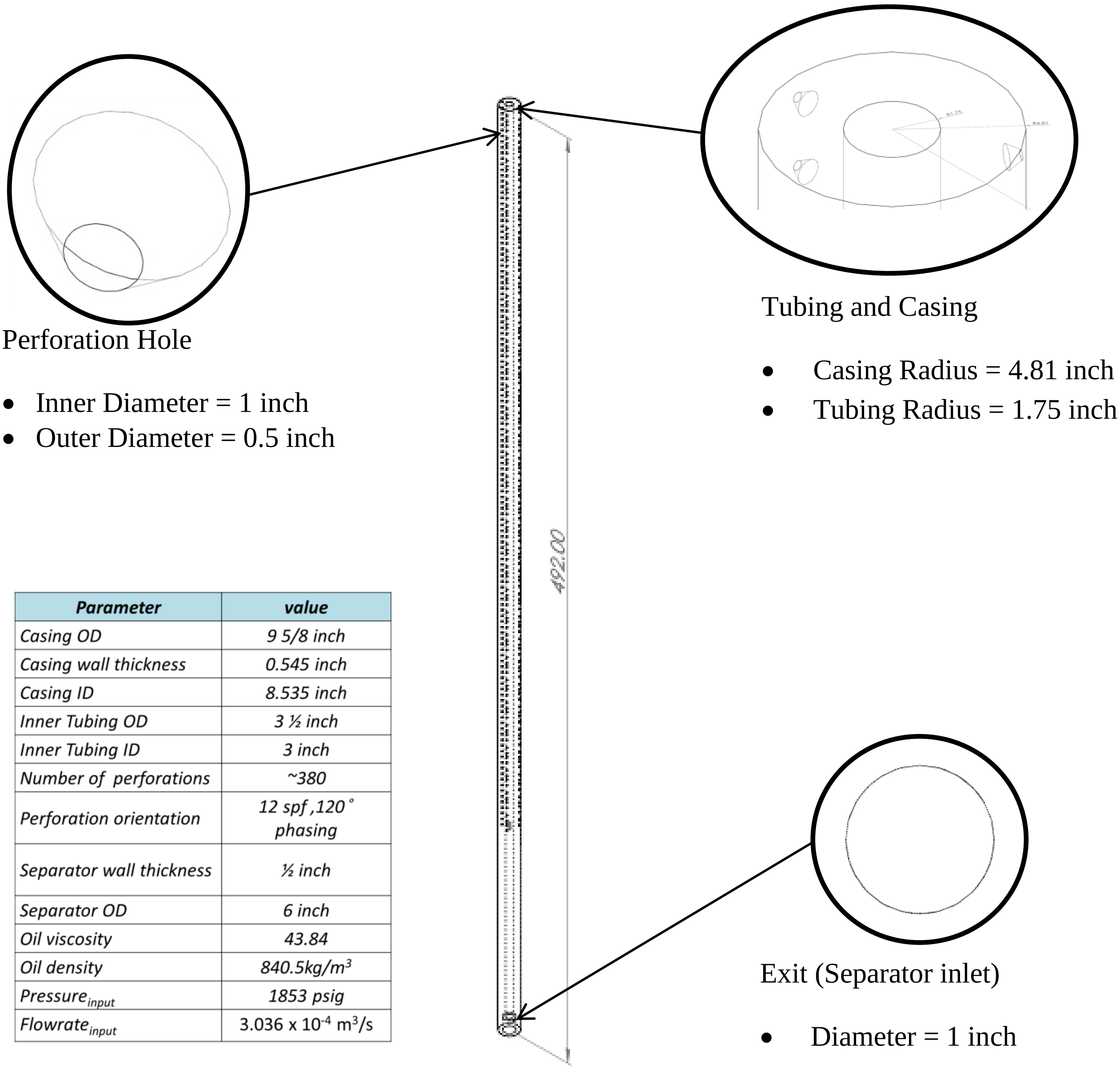
For the project, the software's used is as follow.

a) SolidWorks 2012
b) Fluent 14

3.5 Pre-simulation

Modelling

Since the project is divided into two halves, the modelling part and the simulation part, for FYP 1, the modelling part is being done. Below are models that were constructed during the FYP 1.



Parameter	value
Casing OD	9 5/8 inch
Casing wall thickness	0.545 inch
Casing ID	8.535 inch
Inner Tubing OD	3 ½ inch
Inner Tubing ID	3 inch
Number of perforations	~380
Perforation orientation	12 spf ,120 ° phasing
Separator wall thickness	½ inch
Separator OD	6 inch
Oil viscosity	43.84
Oil density	840.5kg/m³
$Pressure_{input}$	1853 psig
$Flowrate_{input}$	3.036 x 10^{-4} m^3/s

Figure 3.3 : Tubing Model

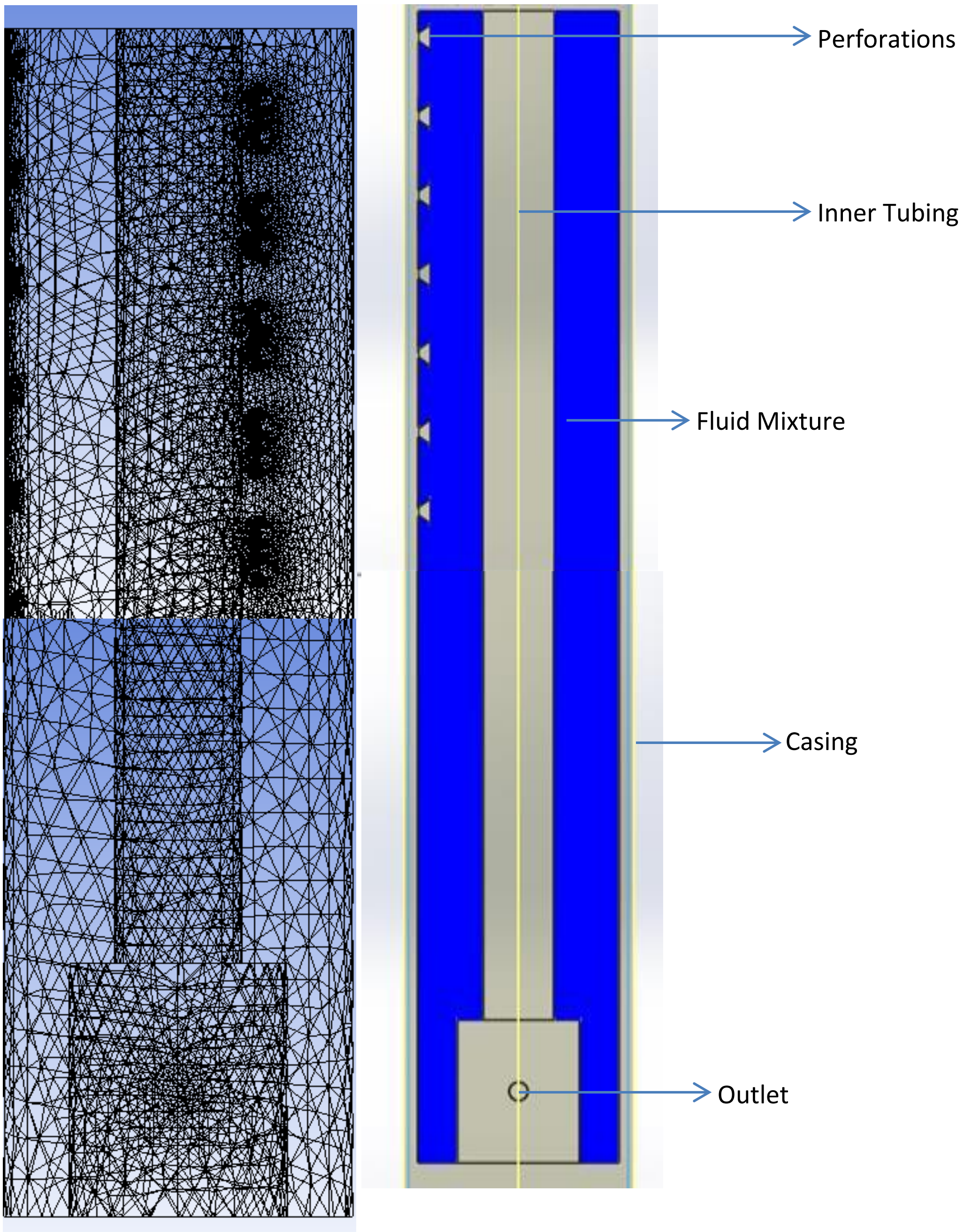


Figure 3.4 : Cross-section and Mesh of Model

As illustrated, the water and oil from the oil reservoir will be entering the well through the perforated holes on the wall. The mixture then exits through the hole at the bottom, which is depicted in figure 3.4. The simulation will be the whole process of the mixture flowing from the perforations into the exit hole below, where the simulation will depict the course that the mixture will take, the nature of the flow, stress induced by the flow and also how the mixture exits into the hole below.

The parameters used for the model is based on the casing modelled as 9 5/8" 53.5# P-110 Range 3; 9 5/8 inch OD, 0.545" wall thickness, 8.535" ID and 41-feet in length. Inner tubing OD is 3 ½". 12 spf (shot per foot) with 120^o phasing. And separator wall thickness of ½", OD of 6".

Simulation

For the simulation, 3 different flow ratio was used, 100% oil, 50% oil: 50% water, and 30% oil: 70% water. The reason we use these set of data is to see the flow characteristics as the flow pattern changes from oil-dominated towards water-dominated.

For the parameters of the water, a search through the internet yielded most of the wanted values. For the parameters of the crude oil, several equations are used to determine the wanted parameters. Below are the calculations.

Viscosity

Given the oil API, G = 36.9, Temperature, T = 60 F, using the Beggs and Robinson equation

$$\mu_{od} = 10^x - 1$$

Where:

$$x = y\,T^{-1.163}$$
$$y = 10^z$$
$$z = 3.0324 - 0.02023\,G$$

We get the value of viscosity, μ_{od} = 43.84

Density

Given the density of crude oil, 40 API @ 60 F = 825 kg/m^3

and

35.6 API @ 60 F = 847 kg/m^3

Using interpolation, the density of crude oil, 36.9 API @ 60 F = 840.5 kg/m^3

The simulations are divided into three main phase which is meshing, Set-up and solution, and finally calculate and results.

K-epsilon turbulent model,

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k + P_b - \rho\epsilon - Y_M + S_k$$

and

$$\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_i}(\rho\epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}(P_k + C_{3\epsilon}P_b) - C_{2\epsilon}\rho\frac{\epsilon^2}{k} + S_\epsilon$$

and

Schiller-Naumann drag model,

$$f = \frac{C_D Re}{24}$$

where

$$C_D = \begin{cases} 24\frac{(1+0.15\,Re^{0.687})}{Re} & Re \le 1000 \\ 0.44 & Re > 1000 \end{cases}$$

is used.

From the data obtained, the flow rate of the fluids entering the perforation is 165bbl/day or 3.036 x 10^{-4} m^3/s and the pressure of the fluids entering is 1853 psig or 12877310.24395216 Pascal.

The data that is used as reference in the simulation is from the Bayan oil field in Sarawak.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results

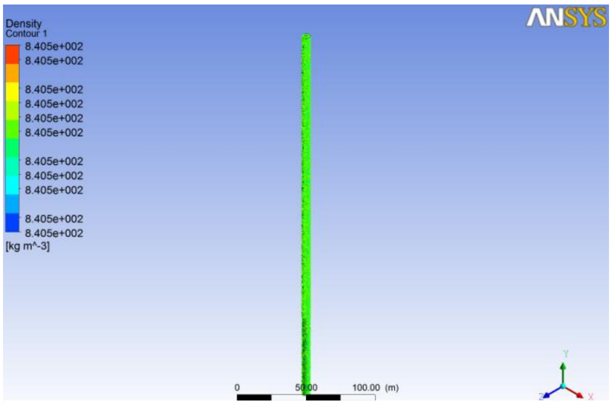


Figure 4.1 : Density at 100% oil

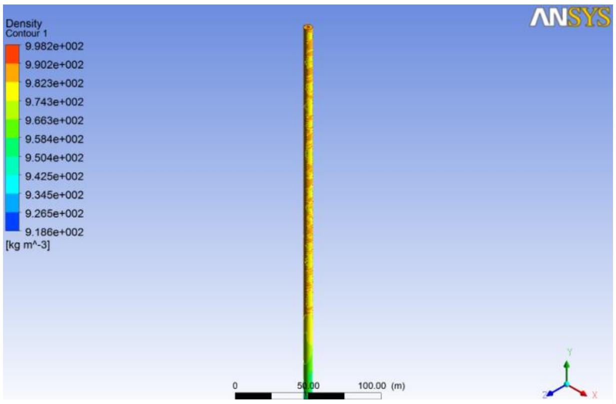


Figure 4.2 : Density at 50% oil

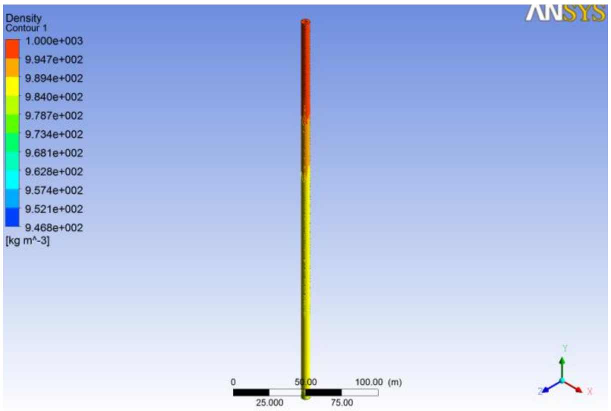


Figure 4.3 : Density at 30% oil

The figure 4.1, 4.2 and 4.3 shows the density distribution of the fluid(s). From the contours shown in figure 4.1, figure 4.2, and figure 4.3, a transition can be seen as the mixture of water and oil starts to change. In each figure, the density starts as the highest, being the density of water, and starts to decrease as it goes down. This is represented from the colours, where red is the highest density, followed by orange, yellow, light green, dark green, light blue, and finally dark blue which is the lowest density.

In figure 4.1, we can see the density of oil being uniform throughout the flow. This is because there is no mixture in the flow. When we see the contour arrangement in the 50% oil, we can see that the density is varying as it goes down, and finally starts to settle as it reaches the end. This may be caused by the tendency of the fluids to be balanced throughout the flow, so we have a density distribution as such. In figure 4.3, the distribution is quite clear, from the density of water to slowly turning into the density of the 2 mixture.

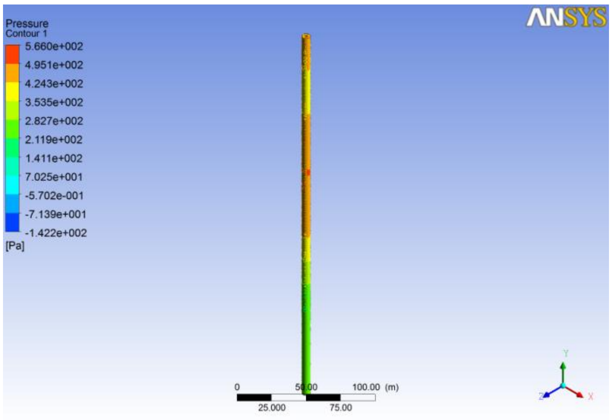


Figure 4.4 : Pressure at 100% oil

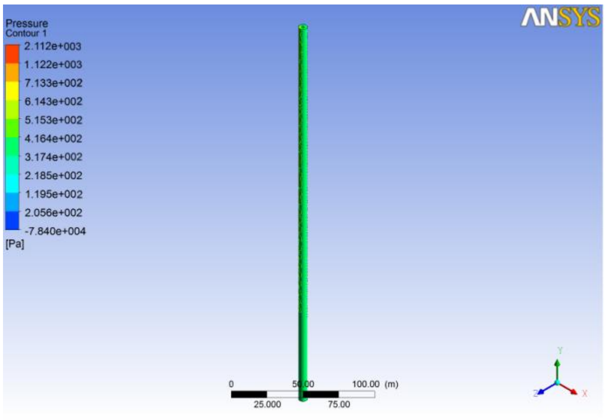


Figure 4.5 : Pressure at 50% oil

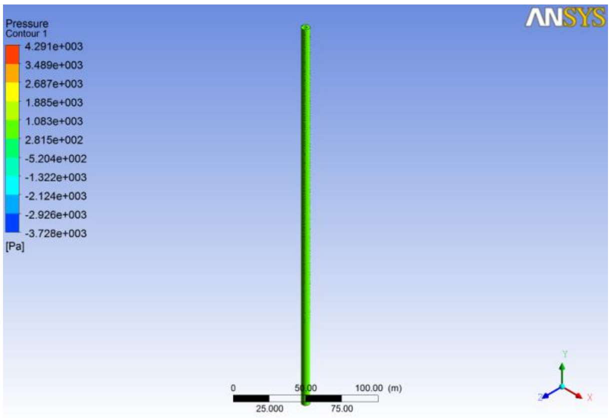
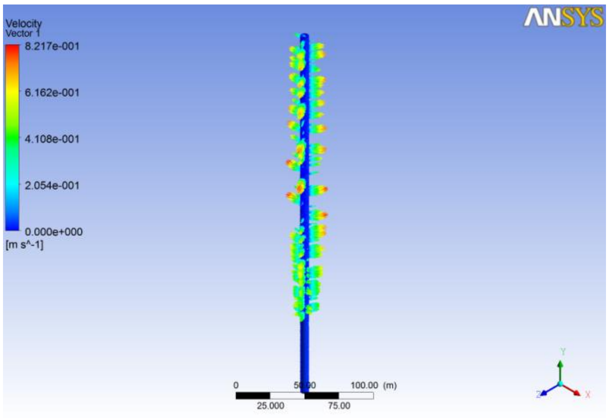


Figure 4.6 : Pressure at 30% oil

The figures 4.4, 4.5 and 4.6 show the pressure distribution of the fluid(s). from the figures, we can see the difference of the maximum pressure between the 3 oil volume fraction is quite high. Again, the pressure distribution is represented by the colour of the contour of the simulation, Red being the highest pressure parts and dark blue being the parts where pressure is lowest.

In figure 4.4, the pressure distribution can be seen as uneven, where the perforations part have different pressure regions and the lower part have a uniform pressure difference. In figure 4.5 and figure 4.6, we can see a uniform pressure contour distribution. The pressure exerted throughout the pipeline is the same with several parts having higher pressure than others.



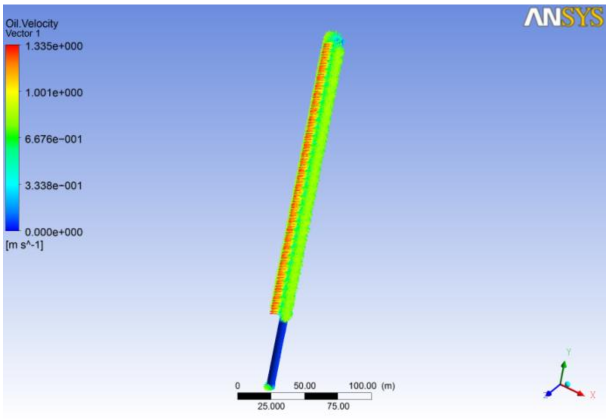


Figure 4.7 : Velocity vector of oil at 100% oil

Figure 4.8 : Velocity vector of oil at 50% oil

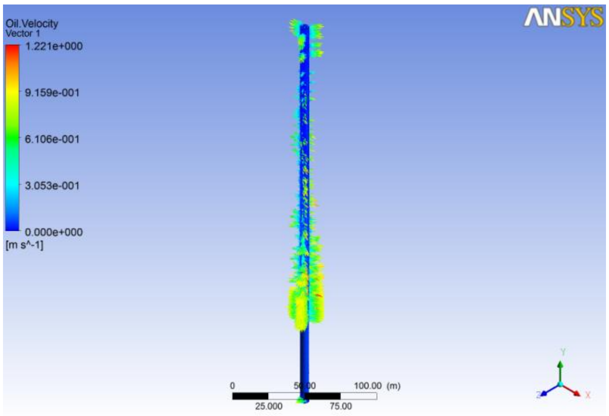
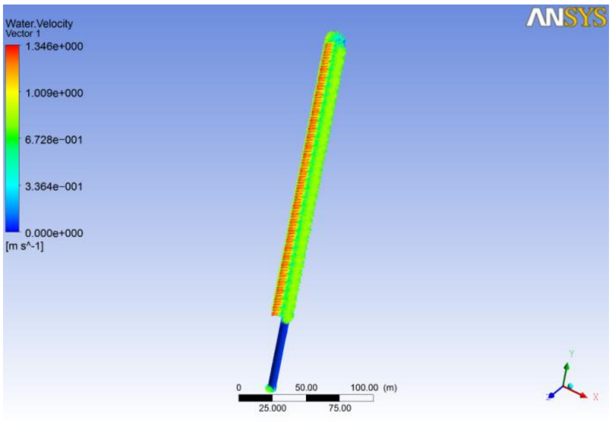


Figure 4.9 : Velocity of oil at 30% oil

Figure 4.7, 4.8 and 4.9 shows the distribution for the oil velocity of the different oil volume fraction. From the figures, we can see that for velocity, vector is used instead of contours. This is to see the flow velocity entering the perforations and exiting. The velocity vectors are also colour coded like contours, where red is the highest velocity and dark blue the lowest.

In all the figures, we can see that the velocity of the fluids start to decrease as it goes into the perforations. This may be caused by the stopping of the fluids by the walls as it tries to enter the perforations, thus reducing the momentum of velocity. Since the velocity entering the perforations is the green contours, we do not use the maximum velocity of the fluids for our results, but instead we use the value of velocity at the green contour.



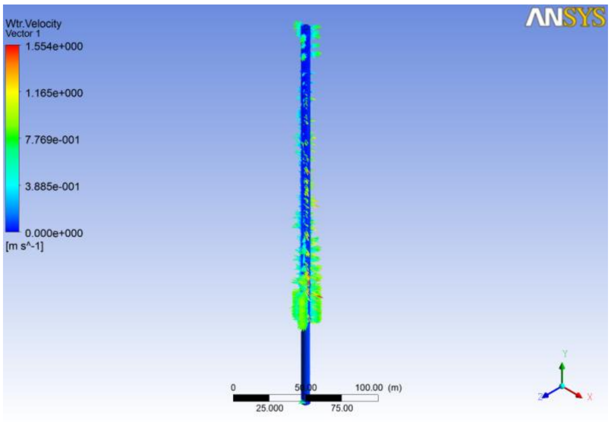


Figure 4.10 : Velocity vector of water at 50% oil **Figure 4.11 : Velocity vector of water at 30%**

Figure 4.10 and 4.11 shows the distribution for the water velocity of the different oil volume fraction. Just like the velocity for oil, we use vectors instead of contour to show the flow of the fluids into the perforations.

For water, the velocity profile of the green coloured-vectors are used also since the velocity entering is the green velocity and not the maximum velocity.

After the collection of data from the simulation results are done, the following graphs were obtained.

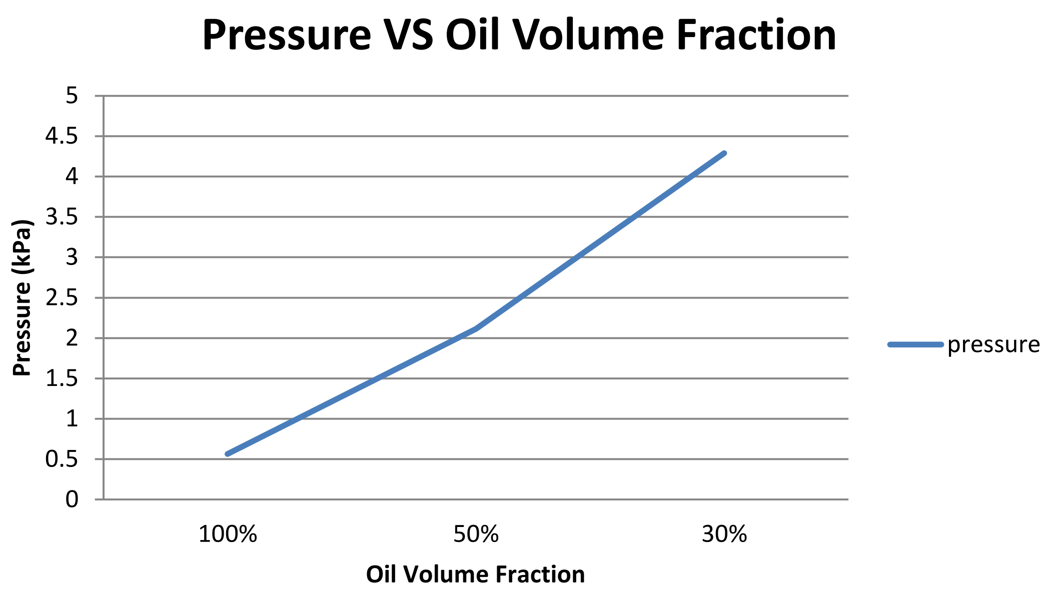


Figure 4.12 : Pressure VS Oil Volume Fraction graph

Pressure plays a big role in the production of oil. A high pressure difference mean there is no need for external source to pump up the oil from the reservoir to the production area at the top.

From the figure 4.12, we can see that as water starts to dominate, the pressure starts to climb as well. This maybe due to oil having a high frictional pressure gradient potential than water, which means water is more easily 'pushed' by the surrounding aquifer through the pipes compared to oil, which have tendency to stick to the wall, causing low flow rate and low pressure.

This show the potential that production with water-dominated flow can be if used in production. A separation technology that uses the pressure difference between downhole and up can surely be a worthwhile investment.

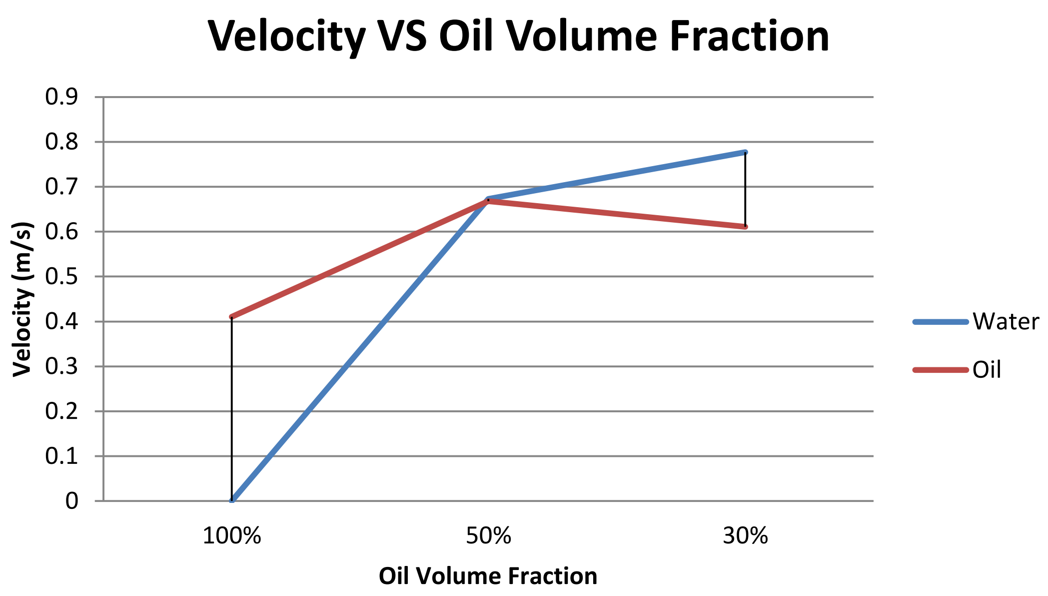


Figure 4.13 : Velocity VS Oil Volume Fraction graph

From the figure 4.13, as the oil volume fraction in the fluid decreases, we can see that the velocity of the water increases. This concurs with the high slippage factor of the water, causing less resistance to the flow of the fluid.

With an increased velocity of water, and a reduced velocity of oil, we can see that a lower oil volume fraction the way to go for the most extraction of oil from the reservoir.

This also shows how pressure direct affects the velocity of fluid flow in a vessel.

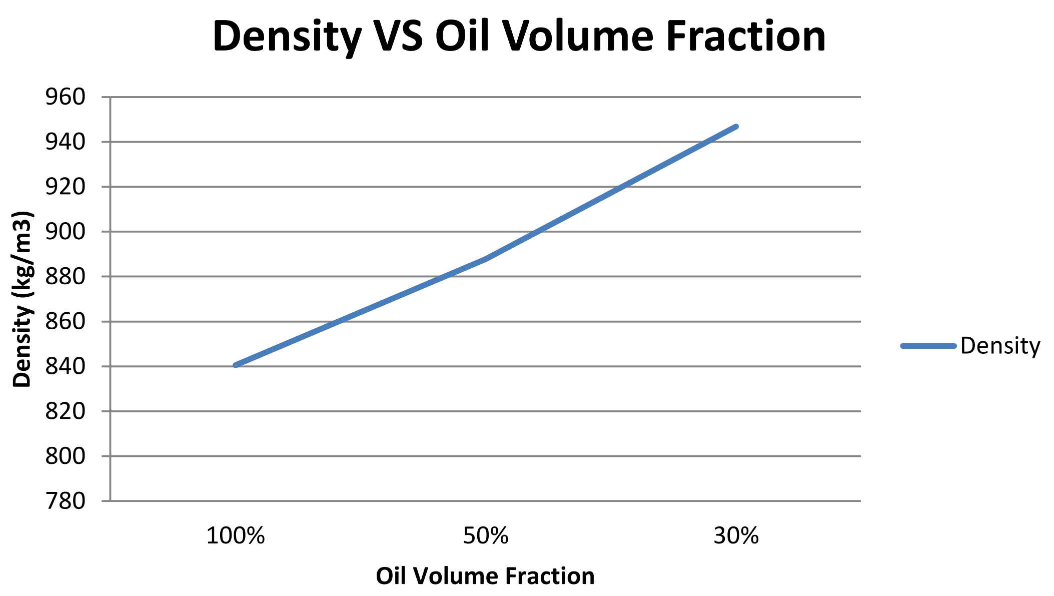


Figure 4.14 : Density VS Oil Volume Fraction graph

From the figure 4.14, we can see that as the ratio of oil and water starts to change, the density of the fluids change together. The above graph was obtained from the simulation and corresponds with the equation

$$Density = (\%\ of\ water\ x\ density\ of\ water) + (\%\ of\ oil\ x\ density\ of\ oil)$$

This also shows the characteristics of oil and water where both of them can't be mixed to form a new fluid. Even during flows where they are mixed together, they still flow as separate fluids.

4.2 Discussion

From the results that we have obtained, and also from the literature reviewed during the whole project, we can see that aside from production cost, the mixture of oil and water in the well can actually have adverse effects on the rate of oil entering the pipeline and flow to the surface.

Since the flow rate into the tubing is controlled, the more water entering would mean less oil being extracted. For a normal production at PETRONAS oil production facility, the production is stopped when the amount of fluid entering is 90% water and 10 % oil. This case is not applied in the UAE.

But, having a water dominated flow proves to be good as well. Even though more water is entering, the pressure difference at entrance and exit is higher than oil dominated flow. This means that the more water dominated a flow is, the higher the flow rate achievable. This is applied in the UAE, where their 10% of oil produced can accommodate the 90% water lost.

Having said that, although water dominated flow is indeed a good ally in a naturally driven drive mechanism, but once the pressure difference starts to drop, that is when oil dominated flows are most wanted. It is said that although the pressure has decreased, there can be potentially 25% - 95% of the oil still being there.

At the end of the day, it all comes down to whether or not continuing to pursue an oil reservoir is worth the price. Although naturally driven oil wells have relatively low cost of production since it is all nature, but there will come a time when even this high pressure starts to decrease.

When this happens, the cheapest extraction technique will be the one determining whether a company can still obtain the same profit margin or will have a deduction in revenue.

CHAPTER 5: CONCLUSION

5.1 Conclusion

Although many obstacles were faced during the simulation process, the wanted results were successfully obtained. The simulation is a naturally driven drive mechanism, where the only driving force for the fluids entering the perforations is the pressure at the downhole. During the simulation, we can see that some of the objectives of the project is achieved, which is to simulate the interaction of oil and water at the downhole, and to analyse the results obtained from the simulations. The objective of writing a conference paper has not yet been achieved.

Hopefully, the project may shed some light of the advantages and disadvantages of water-dominated flow and oil-dominated flow in a production and help with the further development of projects with regards to the separation of oil and water during oil production

5.2 Recommendations

During the course of my project, I have seen several area that can be improved to further enhance the simulation results.

First recommendation is to use topography as a means to visualize the fluid distribution across the pipeline. By just using simulation, an accurate fluid distribution cannot be obtained since simulation is just theoretical. By using topography, a sliced up imagery can be obtained, where we can see how the fluid is distributed in a pipe, helping with the design of a better separation tool.

Second recommendation is to do simulations of inclined pipelines as well. Since inclined pipelines are new to scene of oil well, a simulation of the fluid flow may determine which configuration/inclination is the best.

Third recommendation is to improve the model being used. The model that is used currently is the new model, without any blockage. An actual model from the downhole may have blocked perforation, to block water when the water level has reached that particular level.

Last recommendation is to simulate the fluids entering through the perforations, instead of from the top. During the simulation, several errors were encountered when trying to simulate the fluid entering through perforation. Further knowledge on Fluent is needed for the said purpose.

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