UNIVERSITI TEKNOLOGI PETRONAS

Enhanced Oil Recovery Using Seismic Excitation

Progress report

Final Year Project II

By

Ahmed Mohamed Alaa Abbas Badreldin

15823

Dissertation submitted in a partial fulfillment of the requirements for the Bachelor of Engineering (Hons) for Petroleum Engineering

May 2015

CERTIFICATION OF APPROVAL

Enhanced Oil Recovery Using Seismic Excitation

By

Ahmed Mohamed Alaa

15823

A final year project dissertation submitted to the
Electrical and Electronics Engineering Department
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(ELECTRICAL AND ELECTRONICS ENGINEERING)

JANUARY 2015

Approved by,

(Dr. Shiferaw Regassa)

Dr Shiferaw Regassa Jufar
Lecturer
Petroleum Engineering Department
Universiti Teknologi PETRONAS

ii

CERTIFICATE 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 acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

____

Ahmed Mohamed Alaa

Acknowledgment

I would like to express my deepest gratitude and appreciation to the individuals who have offered their continuous help, guidance, advice and time during the course of this project. The work presented hereby is a result of long working hours and a lot of dedication, however, this dissertation would not have been made possible without them.

First and foremost, my utmost gratitude for Dr Shiferaw Regassa, for his exemplary guidance and monitoring throughout this research project. His sincere advice and dedication motivated me to excel at my work. His challenging questions moved me to explore new horizons on the topic.

Last but not least, to UNIVERSITI TEKNOLOGI PETRONAS for providing me with a nurturing learning environment and advanced facilities that triggered the love of experimenting and discovery within me.

Table of Contents

CHAPTER 1 1

1.1 ABSTRACT 1

1.2 INTRODUCTION & BACKGROUND STUDY 1

1.3 PROBLEM STATEMENT 3

1.4 OBJECTIVES 5

1.5 SCOPE OF THE STUDY 5

CHAPTER 2 6

2.1 LITREATURE REVIEW 6

2.2 MECHANISMS AFFECTING OIL MOBILITY 7

CHAPTER 3 10

3.1 METHDOLOGY 10

3.2 MAIN EQUIPMENTS AND MATERIALS REQUIRED 11

3.4 GAANT CHART 11

3.3 THE PROCESS FLOW 12

3.3 FLUID GEOMETRY MODELLING 12

3.5 ANSYS SOLVER and MESHING 15

3.6 ANSYS Setup and Boundary conditions 15

3.7 BULDING THE SIMULATION AND OIL PATCHING 17

3.8 Coding the seismic waves 17

CHAPTER 4 20

4.1 THEORTICAL VALUE FOR THE DIFFRENTIAL PRESSURE NEEDED TO MOVE THE OIL BLOB 20

4.2 RESULTS OF THE SINGLE OIL SLUG RUN 21

4.3 RESULTS OF THE SINGLE OILSLUG WITH EXCITATION 23

4.4 RESULTS COMPARISON 29

4.5 NEXT STEPS 29

CHAPTER 5 30

5.1 CONCLUSION 30

5.2 RECOMMENDATIONS 30

REFERENCES 32

List of tables

Table 1 : GAANT CHART 11

Table 2 : Calculation for sandstone case 21

Table 3 : Calculation for th current fluid model.. 21

Table 4 : Results comparison 29

List of figures

Figure 1 : Pore throat model for oil blob without excitation 4
Figure 2 : Pore throat model for oil blob with excitation 4
Figure 3 : Sketch of the fluid model on SolidWorks 13
Figure 4 : Full fluid model on SolidWorks 14
Figure 5 : Cross sectional view of the model to ensure no holes 14
Figure 6 : Setup procedure for the meshed model 16
Figure 7 : modeling a trapped oil 20
Figure 8 : Pressure distribution along x-axis 22
Figure 9 : Pressure contours 23
Figure 10 : Dialog box of interpreted UDFs 24
Figure 11 : Phase 2 Volume fraction 25
Figure 12 : Pressure distribution along the excited fluid model 26
Figure 13 : Pressure contours along the excited fluid mode 27
Figure 14 : Velocity distrbution along the excited fluid mode 28

CHAPTER 1

1.1 ABSTRACT

The major factor in increasing residual oil recovery depends on controlling interfacial forces inside the reservoir. In a water wet system, a thin water film covers the matrix material and water forms a continuous phase. When the oil saturation drops below some critical value, it forms a droplets and become dispersed in the water phase. To pass the dispersed droplets through pore throat constrictions, large forces are required. Such large force can be provided by water injection. However, since water is the continuous phase, it bypasses the oil droplets instead of pushing them through the constrictions. A numerical study was performed in order to understand the effect of the seismic waves on the oil droplet trapped in capillary pore throat. The results show that periodic variation of pressure at the pore throat has a nudging effect on the trapped oil drops and in the process it squeezes them through the pore throat constriction.

1.2 INTRODUCTION & BACKGROUND STUDY

Oil recovery in fields is done on several stages, Primary recovery through the natural mechanisms as pressure differences, solution gas expansion, gas cap expansion and water influxes which spaces between 5 % to 15 % of recovery. Followed by secondary recovery through injections of either water or gases as Carbon dioxide, Nitrogen and Steam. A typical secondary recovery will allow for an addition 25 % of recovery. Lastly will be a tertiary oil recover or Enhanced Oil Recovery (EOR) which is done through various chemicals and techniques. Thermal EOR, Chemical EOR and many other techniques are used for this type of recovery. However Igor and Johnson(1994) has mentioned that each of these Enhanced Oil Recovery methods has a number of limitations, as well as some undesirable side effects. Those limitations can vary from economical challenges, environmental challenges or operational challenges [1].

Some of the stimulation techniques need shutting in the production for a period of time while others are costly and not providing economical sustainability. Even speaking on the treatment methods for some of the EOR techniques if not done properly then it may cause ecological consequences. Engineers and geo-physicists are the main ones to face the responsibility of solving such challenges and to search for new method of stimulation. Therefore the suggestion for using elastic-wave stimulation is not being portrayed as a substitute for conventional Enhanced Oil Recovery methods, but as a complimentary tool that can help making conventional methods more effective. [3]

Declining oil production in oil recovery operations is of major concern in oil production industry due to different factors such as very low mobility of oil in pores, decrease of reservoir permeability due to precipitations. Therefore, this paper will be focusing on the EOR done through seismic excitation. Through immobilizing and liberation of the trapped oil droplets seismic stimulation is targeting to enhance oil production. It was found by Pride et al. that for seismic amplitudes above a well-defined dimensionless criterion, the force perturbation associated with the waves indeed can initiate the liberation of the trapped oil on capillary barriers and leaving the pressure gradient to lead the flow [2]. Having the oil trapped in the reservoir after a primary and secondary recovery it will be affected by different forces as the Interfacial tension (IFT), Viscosity, Wettability and Capillary Pressure. This study is aiming to affect the capillary forces to make a positive change of the wettability in the pores in order to increase the oil production. Generally the oil droplets get trapped when the pressure drop is equal to the capillary pressure in pores. In order to break this kind of capillary barrier through the seismic excitation different factors shall be take in consideration as the Elasticity theory for the waves, the size and shape of the oil droplet, the pressure system affecting the whole model. As well as the frequency of the waves, amplitude, energy sources and the time intervals for application

Since the optimum goal of the simulation is to increase the oil production, therefore, choosing seismic excitation due to its low cost and availability rather than other chemicals and EOR methods. The study will take place through 2 main stages, firstly is a simulation study for the model built through assigned software. Secondly will be validating the simulation results through an observational 2D laboratory experiment in order to visually analyze the results. Encouraged by other field tests and laboratory investigations that have demonstrated that high intensity acoustic stimulation may enhance oil recover in rocks [3]. Aiming to be able to transfer the results from a 2D model to 3D modeling in case the study output was effective enough to ensure higher oil production to be done through seismic excitation.

1.3 PROBLEM STATEMENT

In water flooding, the injected water takes the minimum resistance path and residual oil remain trapped in the pore constriction. One of the alternatives to recover such residual oil is through chemicals injection. Such process is complicated and in most cases the result is unpredictable.

Unlike water flooding, seismic waves doesn’t have any preferred minimum resistance path. As such, they may be used to squeeze the trapped oil droplets through the pore throat constriction. The following figures shows the difference before and after applying the seismic waves

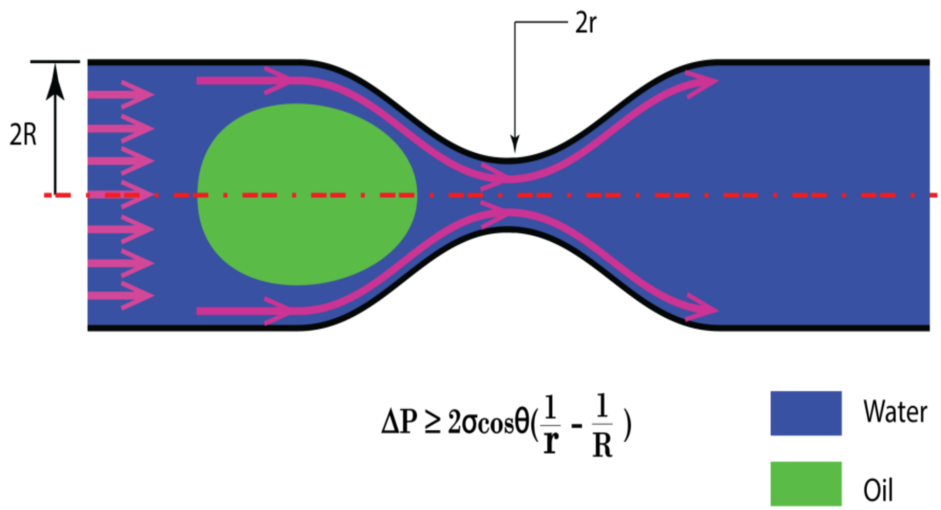


Figure 1 : Pore throat model for oil blob without excitation

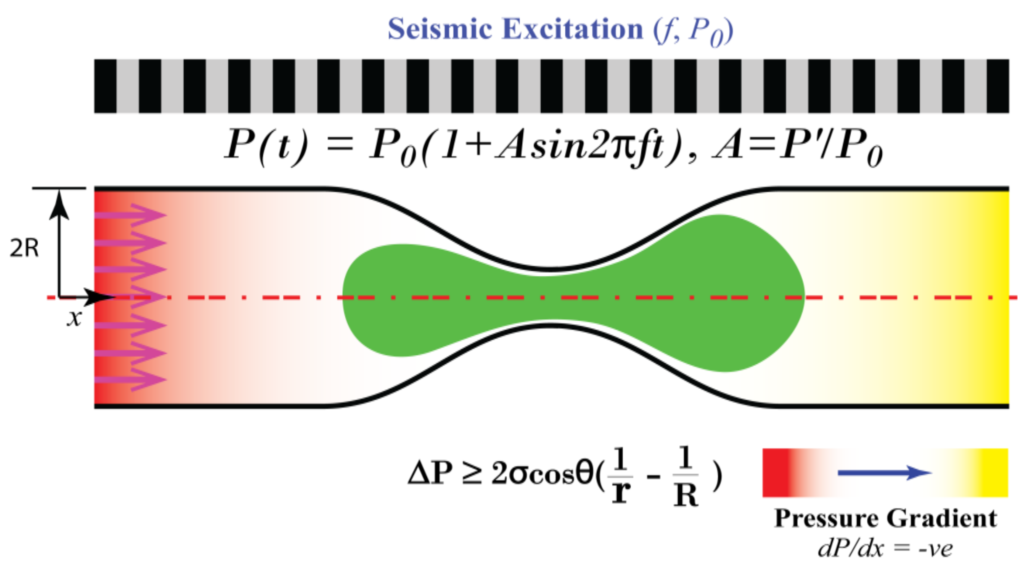


Figure 2 : Pore throat model for oil blob with excitation

1.4 OBJECTIVES

- To study the effect of applying Seismic waves on the trapped oil .
- To study the effect of seismic waves on the pressure change for trapped oil with respect to different pore throat sizes

1.5 SCOPE OF THE STUDY

This study intends to obtain results that are helpful in understanding the nature of interaction between trapped oil blob and seismic excitation parameters so that the overall process can be well-understood before real application. Works are done in the essence of understanding the fundamentals of the process to explain the most influencing mechanisms for such study. In this study, converging-diverging capillary tubes will be used to simulate pore throat geometry of a reservoir rock investigating the effects of seismic excitation on the displacement of oil. Effects of wave parameters as well as fluid properties will be studied using flow visualization. Essentially, the knowledge gained from the present study would be helpful in extending the results to porous media to improve mobility of residual oil left after primary and secondary recovery methods.

CHAPTER 2

2.1 LITREATURE REVIEW

The age of easy oil is fading out that is a fact affecting all the current and prospected oil production plans. Enhancing oil recovery through seismic excitation has been undergoing many studies sense many decades back. Ten years back, Beresnev and Johnson mentioned in a very well explained and detailed paper that in the last 40 years hundreds of observations accumulated principally has shown that the waves created through noise or earthquakes may alter water and oil production [1]. Adding to that multiple researches has found a significant indications about a positive effects for different seismic waves (within different conditions and environments) to participate in enhancing the oil production. The reduction of the interfacial tension forces of the oil-water system and the coalescence of oil droplets inside porous medium to increase mobility found to be one of the main techniques to enhance the oil production through seismic excitation. It was found that ultrasonic waves specifically under specific conditions as in Pressure and Temperature on different fluids can lead to an improvement of oil recovery was observed [5]. Mohammadian, et al. found that when applying a series of straight (normal), and ultrasonic stimulated water-flooding experiments were conducted on kerosene, Vaseline, and SAE-10 (engine oil) using ultrasonic bath in order to enhance the understanding about contributing mechanisms. 3–16% increase in recovery enhancement was calculated [5]. In order to use seismic excitation to increase the mobility of oil droplets inside the rock pores few facts needed to be considered, discussed and studied as follow. Hamida and Babadagali stated more than 10 mechanisms that were found from different researches in order to enhance oil recovery from seismic stimulation [4].

2.2 MECHANISMS AFFECTING OIL MOBILITY

Discussing about the mechanisms led to identifying few techniques or factors that are directly affected under different well conditions by the seismic waves. Speaking about the mechanisms that include the increase in relative Permeability, the reduction in the adherence of wetting phases in rock matrix, the reduction of surface tension, density and viscosity, the oil transport through mechanical vibration. In addition to the effect of coalescence and dispertion of oil droplets to form a bigger size droplet that can liberate through the pores. Surprisingly that seismic wave is not only affecting the oil-water system but an effect can be imposed on the surfactants through increasing solubility of surfactants and reduction of adsorption of surface acting components. Deformation of pores is considered as one of the supporting mechanisms that leads to an increase in the porosity and permeability of the rock. Lastly mentioned by Hamida and Babadagali is the oscillation and excitation of capillary trapped oil drops due to pressure perturbations generated by cavitating bubbles and mechanical vibrations [4].

Understanding about oil mobility in a wetting water system has directed the research into a main factor which is the interfacial tension between oil-water. Studying on how seismic waves can cause a mechanical force to affect the wettability of the rock in addition to the mechanical force exerted to affect the release of oil droplet from such system through the capillary forces. Mohammadian, et al. mentioned that based on Smikin and Odeh, two main mechanisms affect the movement of the fluids in the reservoir; including gravitational forces and capillary forces. The gravitational forces behave on the difference in density between phases saturating the medium [5]. Bersnev and Johnson mentioned that the capillary forces play an important role in liquid infiltration via fine pore channels [1]. It was found that during different experiments and researches done severe temperature rises were observed in the experiments. This leads to reduction in viscosity of fluids as well as reduction in the interfacial tension. The reduction in viscosity of fluid is detected as one of the contributing mechanisms of production. On the other hand, the temperature rises are not high enough to reduce the IFT to a large extent, in other word IFT reduction from temperature rises are so small that cannot contribute in improving the recovery.

Different researches that are mentioned in the references have reported that water flooding or 2 phase fluid systems is the main focus of elastic waves stimulation techniques. Thus studying the effect of vibrations caused by the waves was an in-depth point for enhancing oil recovery production. Supported by Westermark et al. research on paper they have concluded that in an oil-water system The vibration force introduced in the reservoir is thought to facilitate the movement of oil in one or more ways: by diminishing capillary forces; reducing adhesion between the rock and fluids; or causing oil droplets to cluster into “streams” that flow with the water flood [6]. To further strengthen the outcome of the project it was mandatory to refer for some field experiments that have been done to show the effect of seismic or elastic waves on enhancing the oil production.

Supported by different studies it was found that in order to find a potential high outcome in fields it is always preferred to use acoustic waves over ultrasonic waves due to the privilege of longer wave travel acquired from the acoustic waves rather than ultrasonic. De Lacroix et al. have reported that Ultrasonic waves can improve and/or accelerate oil production from porous media. The problem with ultrasonic waves is that in general, the depth of penetration or the distance that ultrasonic waves can move into a reservoir from a source is limited to no more than a few feet, whereas low frequency or acoustic waves can generally travel hundreds to thousands of feet through porous rock [8]. One of the mechanisms causing the enhanced oil production through seismic waves is the effect caused on porosity. Porosity diffusion from low frequency high amplitude waves was introduced by Spanos et al. in his research on flow enhancements. Based on these results, a new liquid flow enhancement technology for reservoirs was formulated, and a successful full-scale field experiment was executed in early 1999. Other field projects in 1999 through 2001 water floods in heavy oil cold production wells with sand influx confirmed the expectation that pressure pulsing, properly executed, increases oil production rate at low cost [9]. Therefore embarking from what the mentioned studies have shown from different mechanisms and high potential on enhancing and increasing the oil production through seismic excitation. This paper will focus on understanding the mechanisms affecting trapped oil in sandstone oil-water system to liberate and move towards the wellbore. It was found that experiments and explanations of the fundamentals of how does the seismic waves can directly affect the capillary forces of the oil droplet can lead to a better applications and technology enhancement for field operations

CHAPTER 3

3.1 METHDOLOGY

The project will be based on understanding the physics of the seismic wave parameters effect on the capillary forces of the trapped oil droplet. To assess those effects and to achieve the project objectives the testing will be taking place in the lab. To ensure a similar environment of the one found in the reservoir exist. The project will be using a capillary tube filled with sandstone, oil and water. After causing water flooding in the tube and stabilizing the oil inside. A seismic wave source will be connected to induce its waves on the capillary tube.

The force and pressure effect done by different seismic waves will be calculated mathematically to calculate the expected change in forces in the oil-water system. Observing the flow of the oil and the w phase fluid flow to analyze the mechanism that has affected the system. Changing conditions will take place for different seismic wave lengths and frequencies to assess and evaluate the effect of each one

The project will be executed on 2 phases. Phase number one will be building a simulation using software to model our proposed laboratory experiment. The built model for the experiment will be representing the desired conditions for the experiment to run and assess the expected changes for the flow. In order to validate the model, the second phase will commence using the desired equipments to do the laboratory experiment and compare the outcomes to the ones performed by the software.

3.2 MAIN EQUIPMENTS AND MATERIALS REQUIRED

1) Fluid Delivery system

2) Flow visualization equipments

3) Seismic source

4) Data acquisition system

5) ANSYS Software

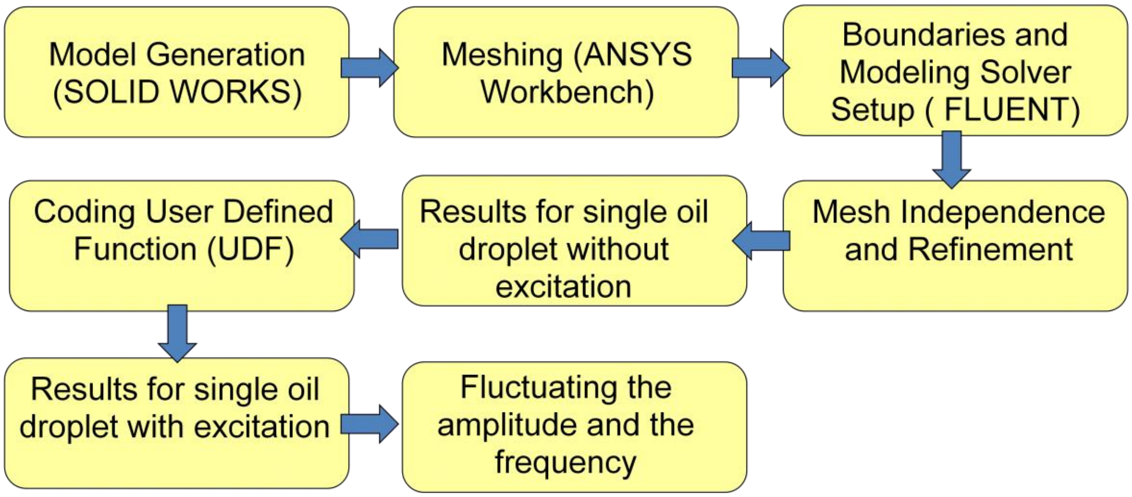
3.4 GAANT CHART

No	Week / Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Designing the simulation	■	■	■	■	■	■	■							
2	Progress Report submission							■							
3	Running comparable simulations								■	■	■	■	■	■	
4	Pre- Sedex										■				
5	Technical Paper submission											■			
6	Dissertation													■	
7	Viva													■	

Table 1 : GAANT CHART

3.3 THE PROCESS FLOW

The flow of the project can be summarized as follow



3.3 FLUID GEOMETRY MODELLING

The geometry in this study will be representing the pore throats within the rock. Thus, converging/diverging tube geometry is to model the fluid. SOLIDWORKS software was chosen to design and model the fluid before importation into ANSYS. Looking through various researches that includes modeling and design it was found that SOLIDWORKS is user friendly with variety of functions that can support accurate 3D modeling for the fluid [9-11]. Using revolving feature was recommended for the model design since it is forming a converging diverging tube. Since the revolving feature needs only designing the upper symmetric half of the model then it starts rotating over the identified axis [12]. The schematic sketch for the model was built as shown in the following figure:

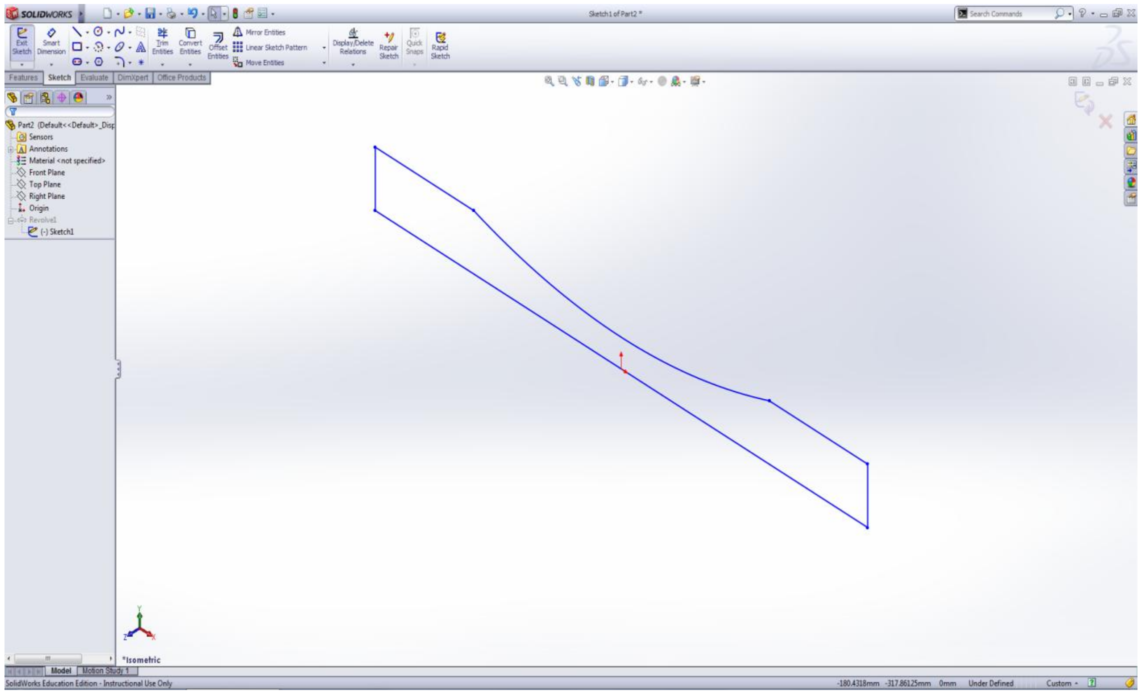


Figure 3 : Sketch of the fluid model on SolidWorks

The concerned pore-throat model geometry through the capillary tube has the following dimensions:

Γmin = 0.025 mm

Γmax = 0.05 mm

L = 0.5 mm

Where (Γmin) is minimum pore throat radius and (Γmax) is the maximum pore throat radius. The length of single pore element will be represented by the symbol L [13]. Revolving the sketch will result in the following modeling to be imported into ANSYS as shown in the coming figures.

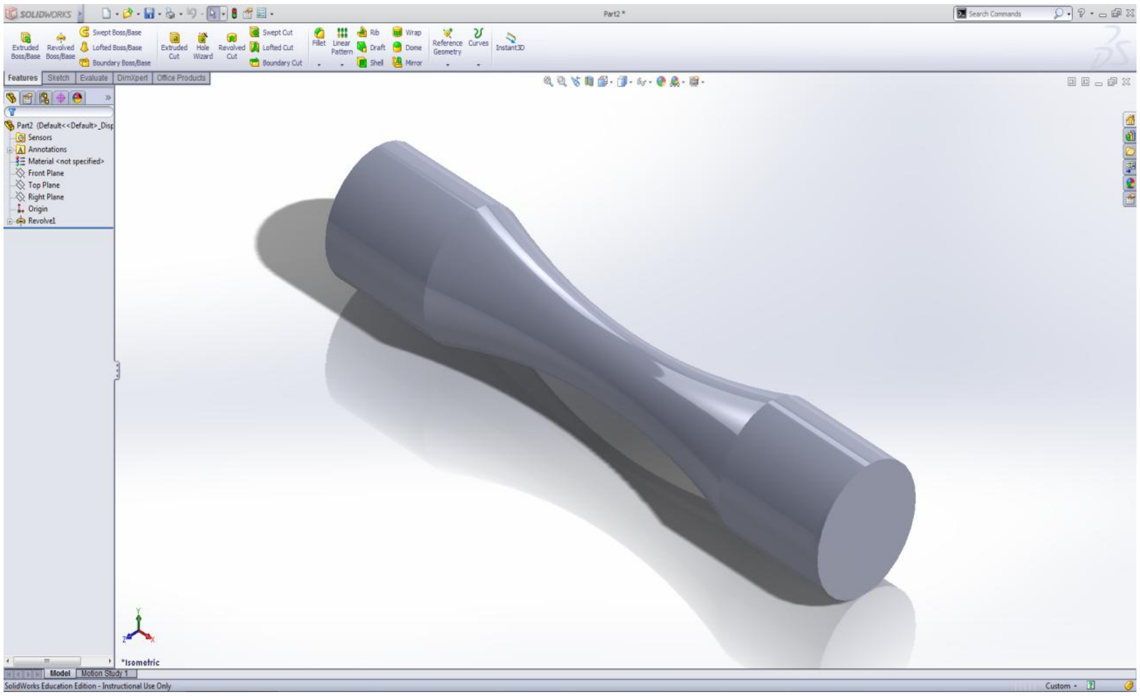


Figure 4 : Full fluid model on SolidWorks

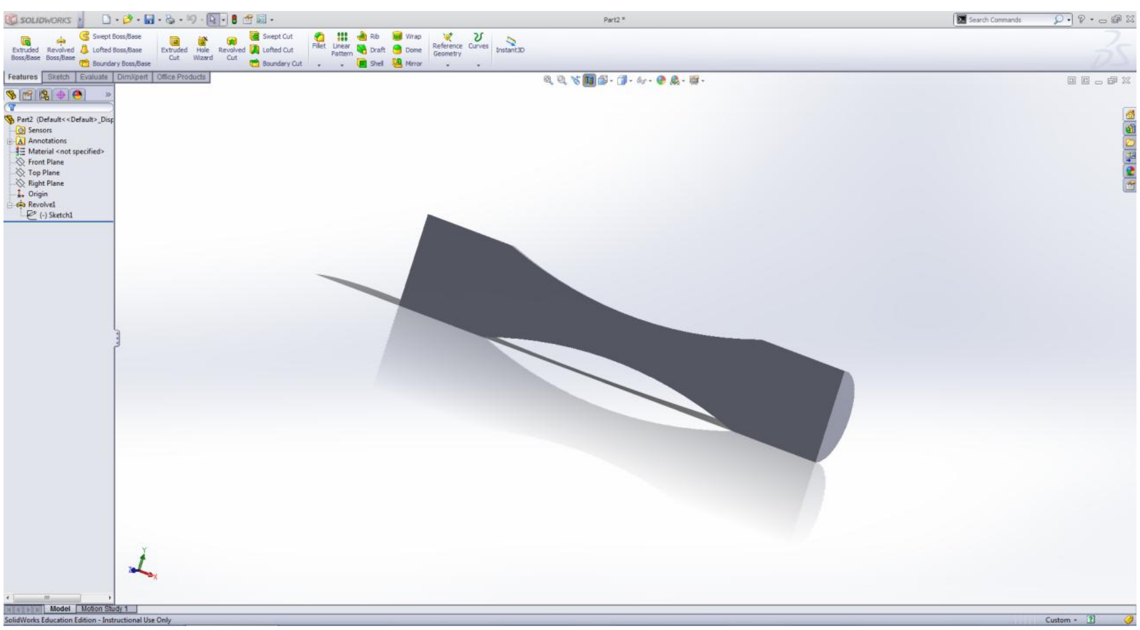


Figure 5 : Cross sectional view of the model to ensure no holes

3.5 ANSYS SOLVER and MESHING

ANSYS-FLUENT has been recommended and used for fluid dynamics solution. Finding different researches for multiphase flow will use fluent due to its ability to model heat transfer, flow and turbulence while offering different approaches to solve the governing equations of motion. Following ANSYS setup a meshing has to be conducted for the inserted model. Meshing was recommended to be 136000 quadrilateral elements for such simulation and conditions [14-15].

3.6 ANSYS Setup and Boundary conditions

Fluent solver for ANSYS has different models to operate and run the calculations. For the designed project and model Multiphase flow – Volume of Fluid will be used due to its ability to stimulate and accurately solve for more the one fluid at time. Volume of Fluid (VOF) is known for its accurate measurement and tracking for wetting film thickness and interface between two merged fluids [15]. In order to get higher accuracy in calculation double precision option s chosen while launching FLUENT. Some major assumptions are made for the setup:

- Laminar flow
- Incompressible fluid
- Gravity effect is negligible

As show in the following figure there are a lot of setups that needs to be done manually in FLUENT. Setups as Identifying Boundary Conditions, Materials, Solving method, and velocity at the inlets and pressure at the outlet of the model are identified for simulating the fluid as sampled in the next figure.

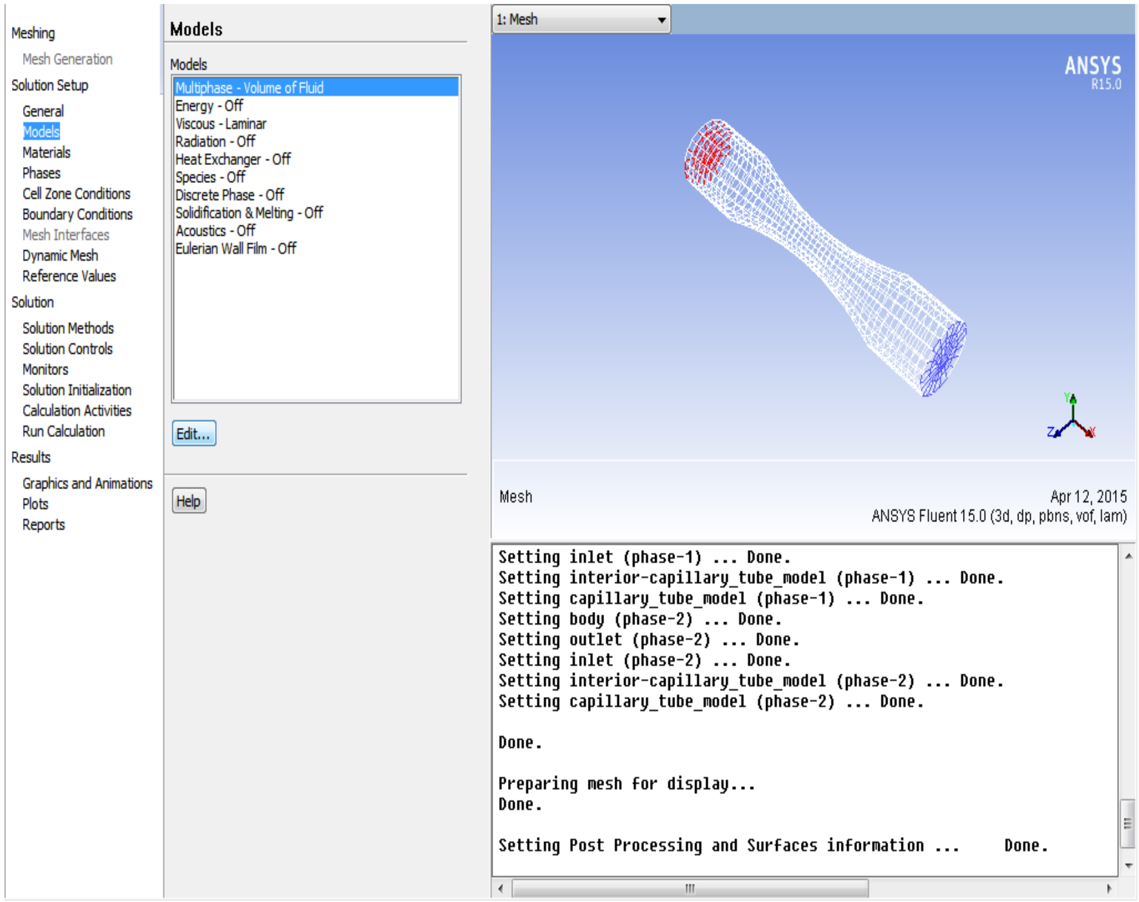


Figure 6 : Setup procedure for the meshed model

A velocity inlet is identified at the right end of the model (blue in color) and Pressure outlet is identified at the left end of the model. Iterations are steady in time and the velocity and pressure configurations to be identified as 10^-7 m/s (x&y velocity) and 0 in order. Two Phases of materials were chosen, first phase is water and second phase is oil. To save the time of the simulation and iterations a first order non-iterative solver was chosen. Other solver options were chosen as follow based on recommendations from ANSYS and other researches [15] [17].

Pressure – Velocity coupling : PISO method

Gradient : Green-Gause node

Pressure discretization : PRESTO

Momentum equation : Quick

Volume Fraction Equation : Geo-Reconstruct

For the sake of experimenting the conditions and preparing for FYP II few runs were done using the current setup for the model, successfully they have generated some results of the calculation showing that the setup procedure was successful.

3.7 BULDING THE SIMULATION AND OIL PATCHING

In order to build the simulation an oil droplet must be patched in the solution solver. As for the initial conditions to start the simulation having a plugged oil droplet inside the pore throat interacting with the injected water. For an oil droplet to be patched an region has to be identified, marked and then patched from ANSYS (FLUENT) [15][16]. The oil droplet used is in radius of 0.05 mm.

3.8 Coding the seismic waves

In fluent there is no option to add seismic waves straight forward. In order to add the vibration that will occur by the seismic waves it is needed to use User Defined Function (UDF). According to ANSYS FLUENT UDF guide, it is defined as C function that can be dynamically loaded with the ANSYS FLUENT solver to enhance its standard features. It can be used either to customize boundary conditions, material property definitions, surface and volume reaction rates, source terms in ANSYS FLUENT transport equations, Enhance post processing and others as well including defining different profiles. In order to add the UDF there are two ways, either using compiled UDFs or Interpreted UDFs. In our project interpreted UDFs are used in order to simplify the process since it doesnot need any C compiler and is limited to C programming language which can be easily interpreted and written.

Establishing the UDF for the seismic wave effect has three main options after a careful study for the best of it, as follow are the three suggested methods :

1) Defining a moving wall boundary under the UDF effect

2) Defining an energy source that affects the wall of the tube
3) Defining the pressure profile change through mathematical equation

In this project option three “Defining the pressure profile change through mathematical equation “ to simplify the code initialization. ANSYS FLUENT has its own coding language and terms in order to interpret. For defining a new profile “ DEFINE_PROFILE “ is chosen. “ DEFINE_PROFILE “ is used to define custom boundary profile or cell zone condition that varies as a function of spatial coordinates or time. For instance, velocity, pressure, temperature, mass flux, volume fraction, wall thermal conditions, porosity, wall roughness conditions, wall shear and stress conditions,,etc.

The main equation used for this code was for the sine wave :

$$P = P^{\circ} + A * SIN\ (2 * \pi * f * t)$$

Where P stands for the pressure, P° stands for the initial pressure, A stands for amplitude, π stands for PI (3,14), f for frequency, t for time.

Therefore the developed code was written as follow in order to implement the effect of the vibration :

```
#include "udf.h"

DEFINE_PROFILE (New_Pressure, d,i)

{

Thread *d;

face_t f;

real t = CURRENT_TIME;
```

```
begin_F_LOOP(f,d)
  {
    F_PROFILE(f,d,i) = 101325.0 + 5.0*sin(2*3.147*2.*t);
  }
end_f_loop(f,d)
}
```

Amplitude were chosen to be 5 for this project.

CHAPTER 4

4.1 THEORTICAL VALUE FOR THE DIFFRENTIAL PRESSURE NEEDED TO MOVE THE OIL BLOB

If an oil blob is trapped at the converging diverging capillary tube model, it will require a minimum pressure to be released following this equation

$$\Delta P \geq 2.\partial.\cos\theta\ (1/r - 1/R)$$

Where P is for Pressure, ∂ is for interfacial tension, θ is the angle, r is for the oil blob radius and R is for the throat radius. According to researches, if it is assumed a sandstone throat r= 50 micrometer and R= 250 micrometer [18].

The following figure represents the model and trapped oil at the existence of water flooding.

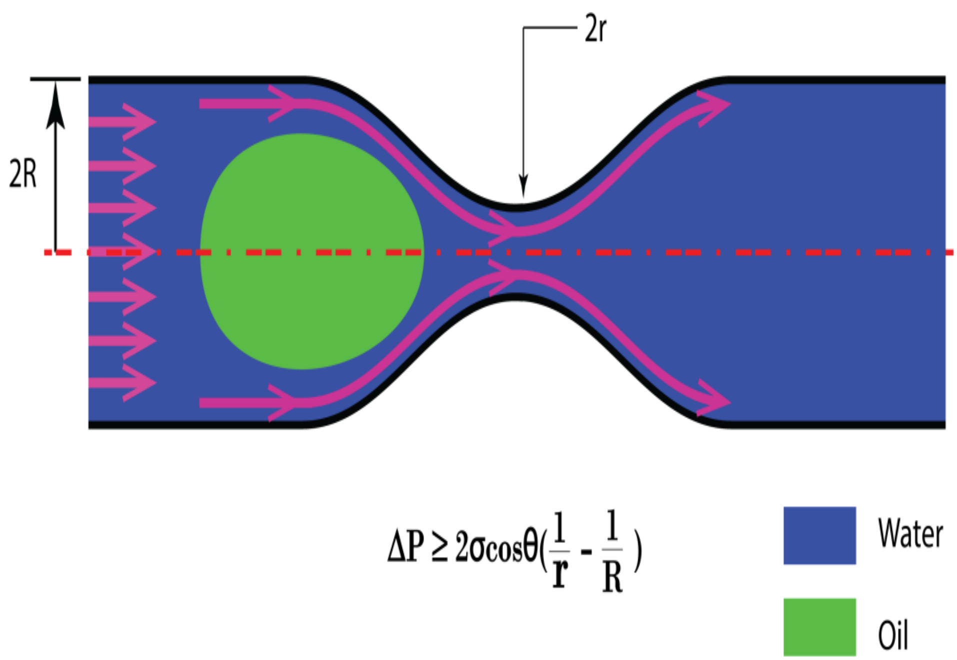


Figure 7 : modeling a trapped oil

Assuming the highest angle, theoretical calculation using the following data for sandstone is summarized in the following table

Parameter	Value
∂	0.02
r	50*10^-6
R	250*10^-6
ΔP	640

Table 2 : Calculation for sandstone case

As for the current fluid model dimensions the following theortical calculation were obtained :

Parameter	Value
∂	0.02
r	0.025*10^-3
R	0.05*10^-3
ΔP	800

Table 3 : Calculation for th current fluid model

4.2 RESULTS OF THE SINGLE OIL SLUG RUN

To assess and analyze the results of the simula.tion there are many parameters that needs to be considered. After successfully building the experiment few simulations took place. Each simulation will last between 6 to 13 hours depending on the time steps chosen for the simulation. Pressure, velocity, phases and other data can be included to interpret the result. The simulation showed the pressure distribution along the tube as follow

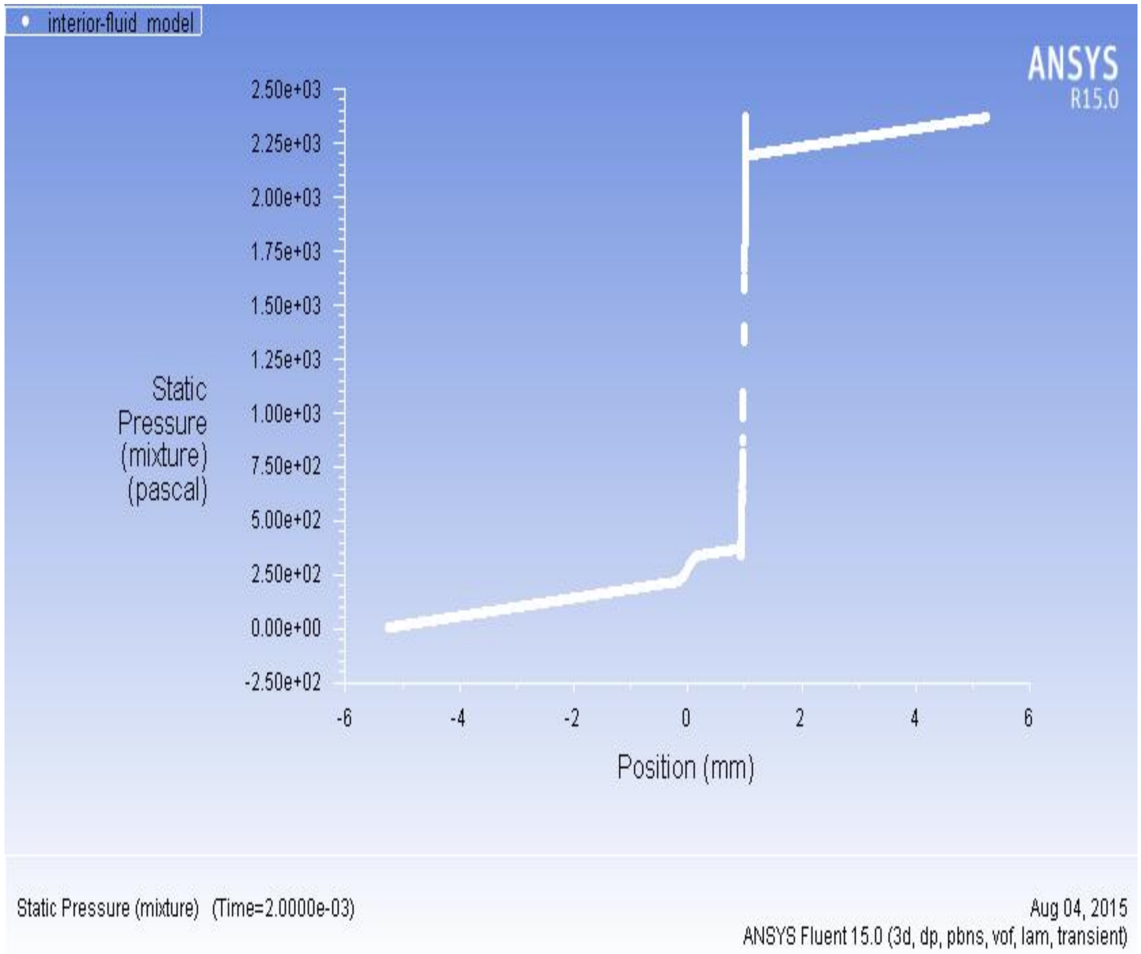


Figure 8 : Pressure distribution along x-axis

In which we can see that Pressure will start from the inlet with 0 Pascal as operating conditions and will keep decreasing at the beginning of the tube until it reach a kind of consistency after it passes the middle of the tube.

Another way to show the pressure change inside the tube is to draw a contour of the pressure distribution along the tube. The following figure explains how the pressure propagated in the tube during one of the runs.

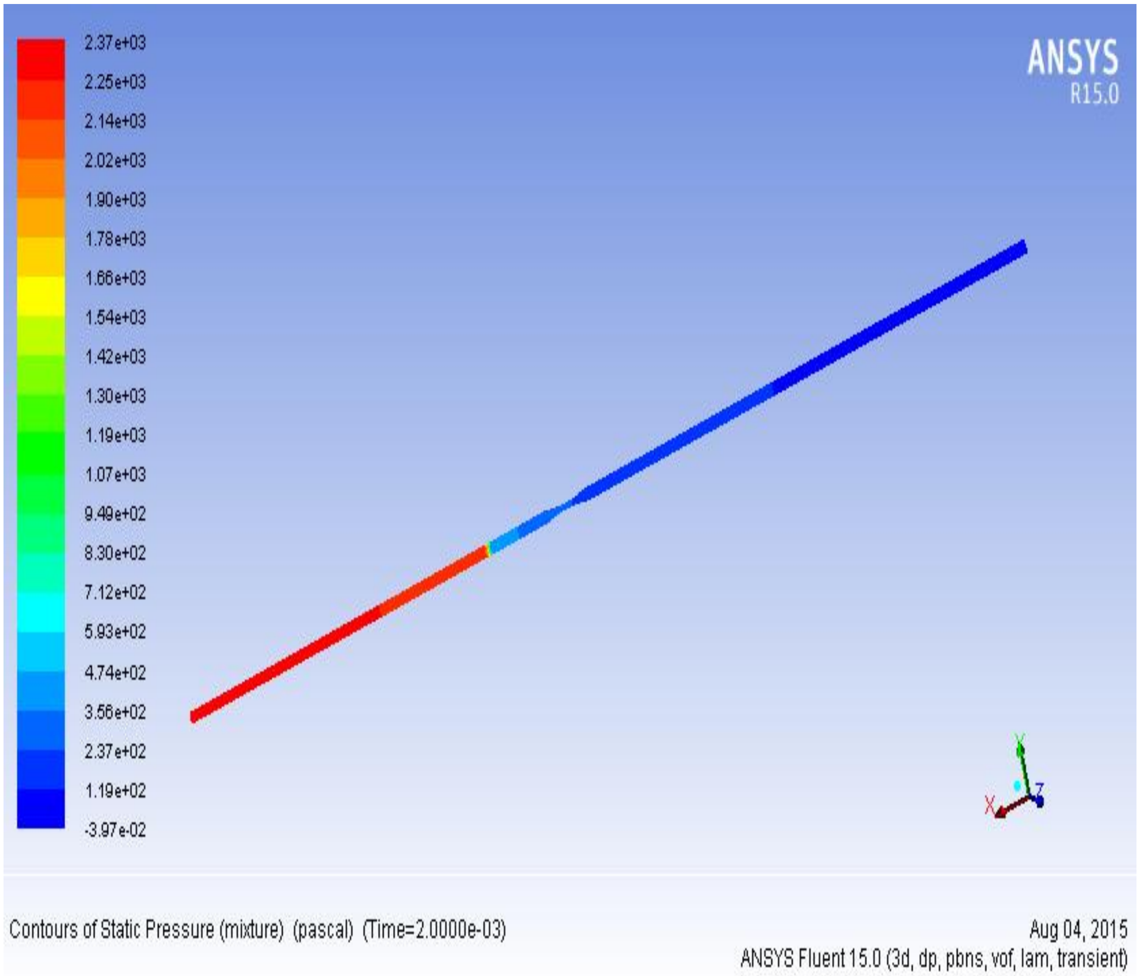


Figure 9 : Pressure contours

4.3 RESULTS OF THE SINGLE OILSLUG WITH EXCITATION

For such case, we will be using the same boundary conditions, same solution method and same initial values. However, the main difference will be in adding the User Defined Function to apply the effect of a sine wave on the tube. In order to apply the UDF firstly, the code is written in a notepad and saved at the file location source. Then from " Define " then choose " User Defined Function " then choosing " Interpreted ". A dialog box will appear as shown in the figure

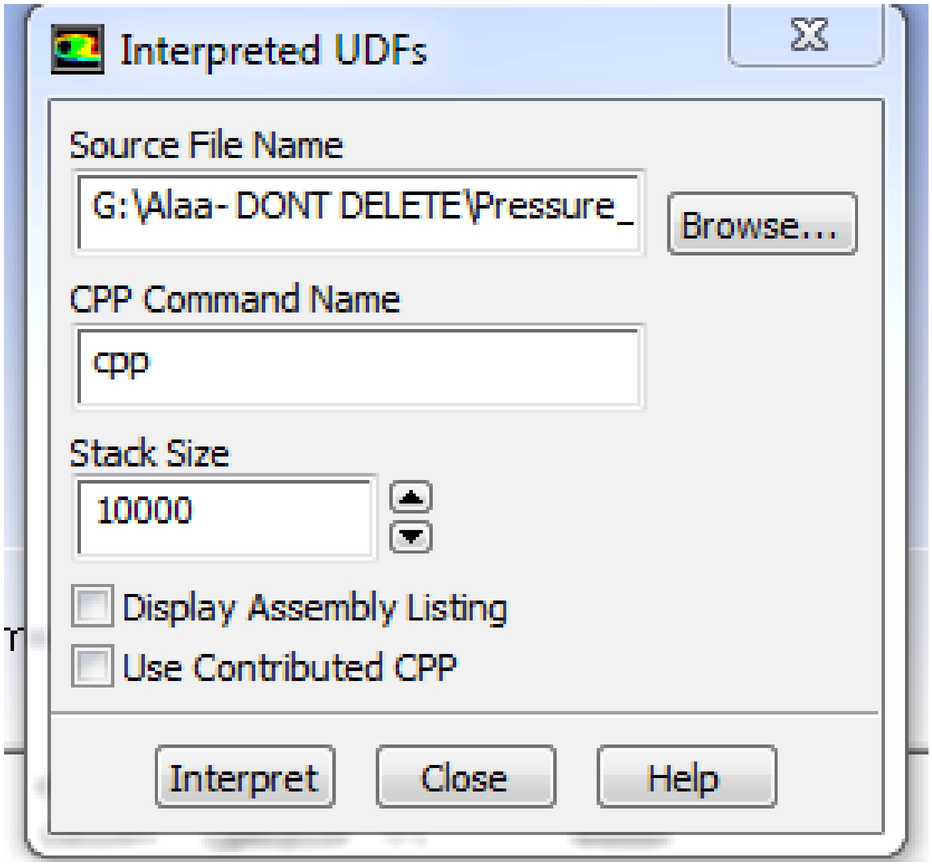


Figure 10 : Dialog box of interpreted UDFs

A quick check for the UDF will run to ensure its effectiveness and freeness of technical errors.

In order to ensure that the simulation was done correctly, a check on the volume fraction of the simulation was done as shown in the next figure. If the volume fraction of phase 2 liquid which is oil is constantly zero and increases to one at certain point where the oil blob existed then this means the set up for the experiment was done and achieved correctly. Therefore the simulation resulted in the next figure :

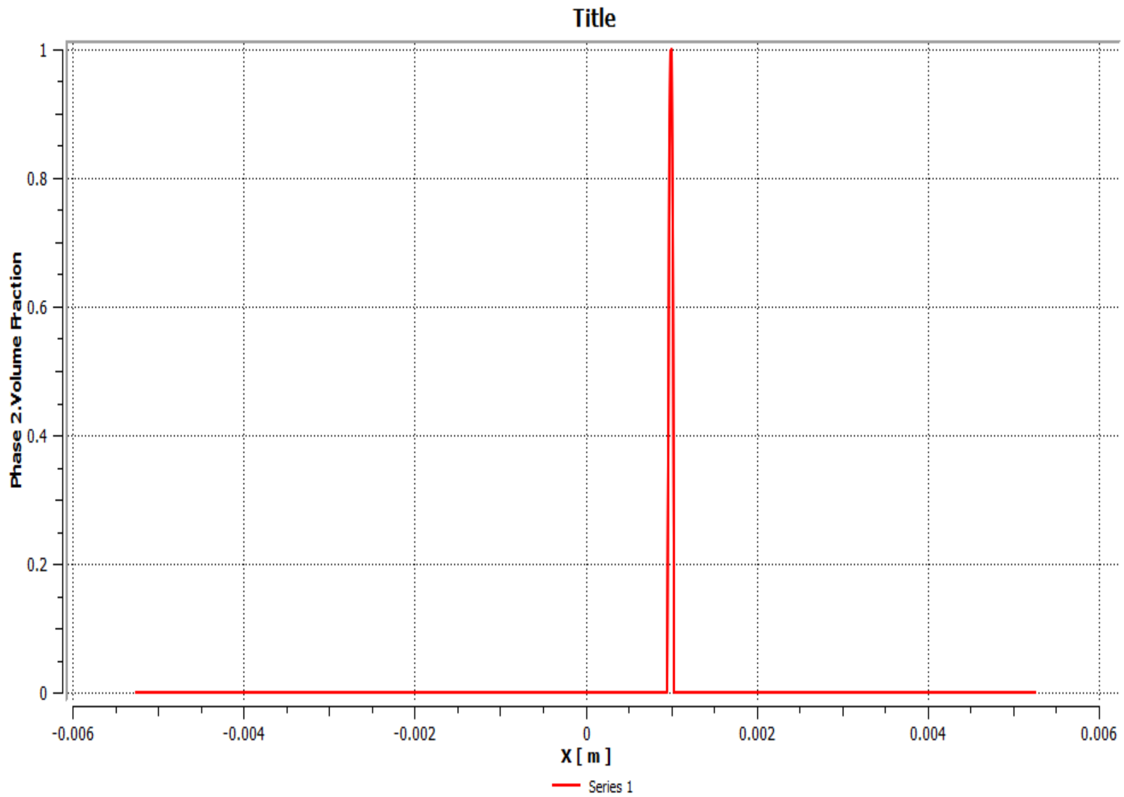


Figure 11 : Phase 2 Volume fraction

After successful iterations, the out come of the simulation will be presented by the next figures :

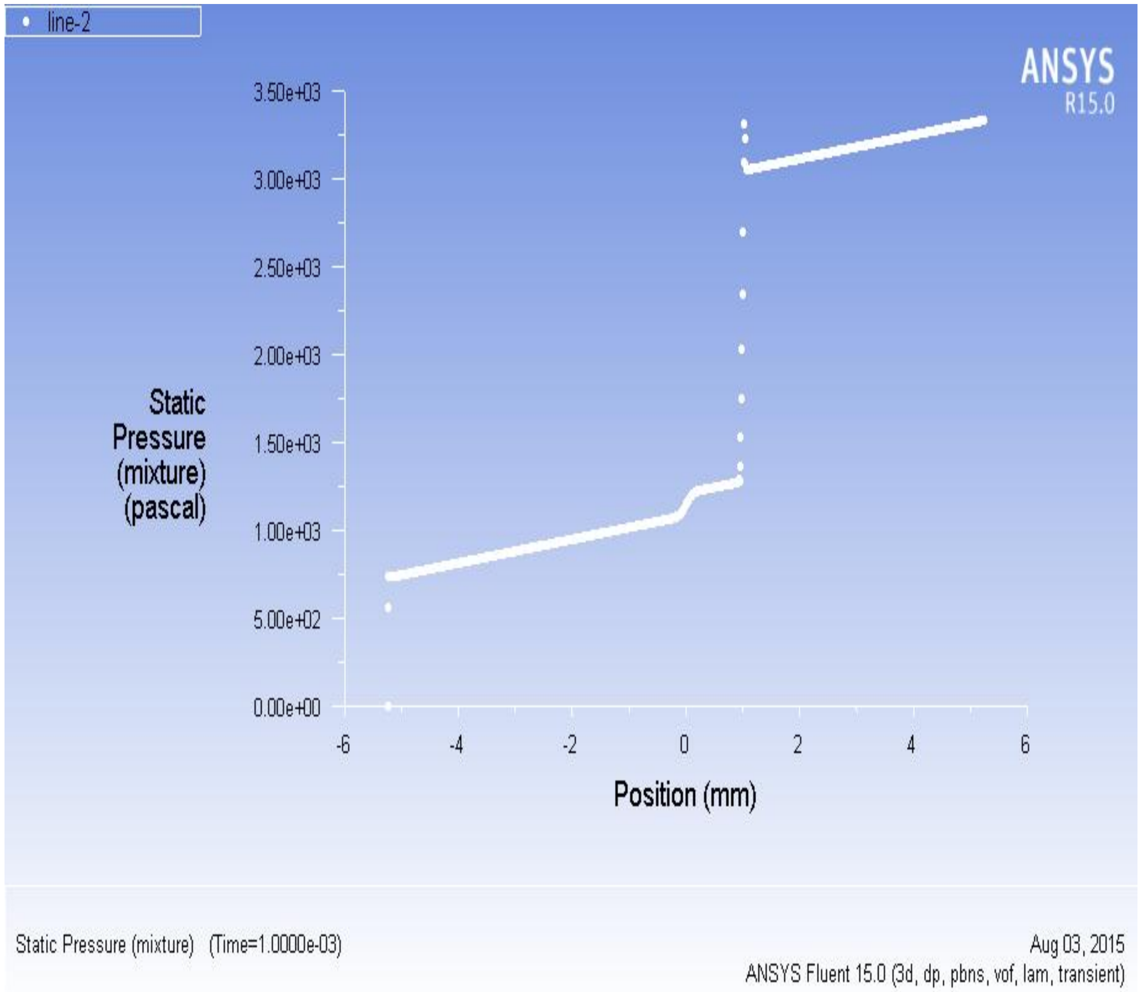


Figure 12 : Pressure distribution along the excited fluid model

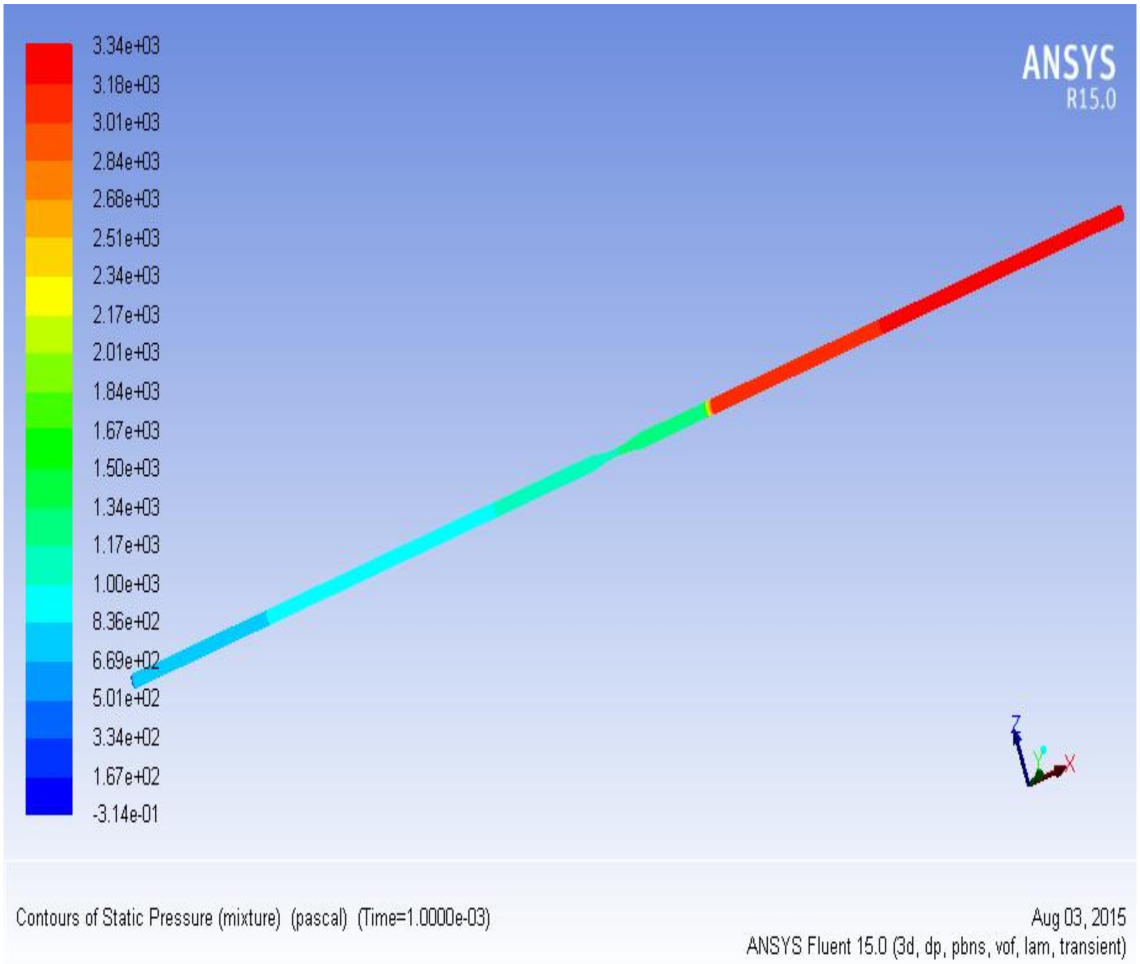


Figure 13 : Pressure contours along the excited fluid mode

From the previous figures it was found that the pressure distribution along the excited model was way higher than the previous one. Pressure difference varies from 500 Pa at the inlet up until 3500 Pa at the outlet. From the pressure distribution you can find that pressure trend starts to change at the zero position where the model radius start to decrease. The second trend change takes place at the placed oil droplet where the pressure dramatically changes and rise due to the existence of the oil blob. Along the pressure contours the place of the oil droplet is marked differently in yellow just before the red contours.

Next figure shows the velocity distribution along the tube resulted from the simulation.

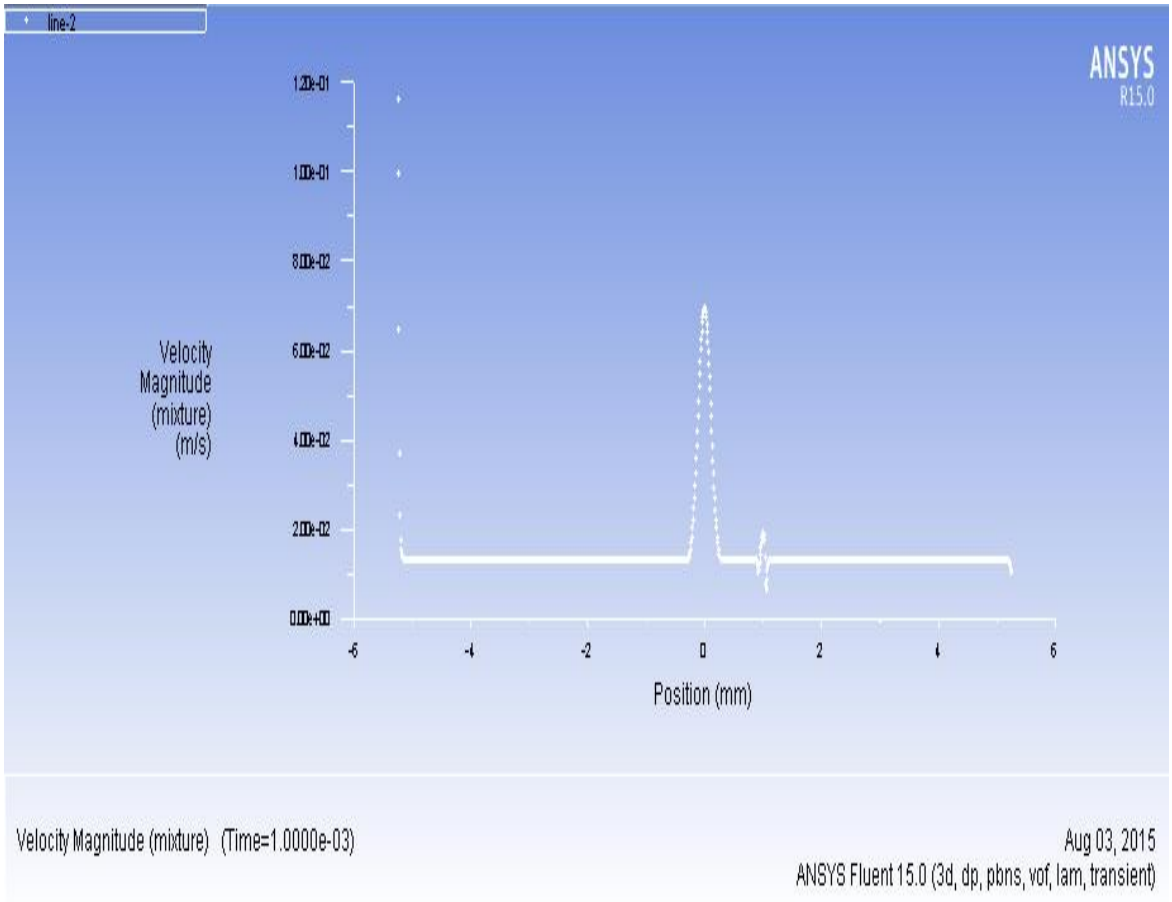


Figure 14 : Velocity distrbution along the excited fluid mode

It is seen from the distribution that the velocity profile fluctuates at two points. One from which the radius of the model narrows and the other one at the position where the oil blob is placed and located.

4.4 RESULTS COMPARISON

Case	Obtained Pressure (Pa)
Current Model Theortically	800
Sandstone Theortically	640
Simulation without excitation	500
Simulation with excitation	1100

Table 4 : Results comparison

From the previous table it is figured out that the pressure obtained after excitation of the fluid model is higher than the minimum pressure required to squeeze the oil blob in the current model or in the sandstone reference.

4.5 NEXT STEPS

In order to move on an camera feature should be added in the simulations in order to capture the movement of the oil droplet and the water film, which hwas no applicable in the previous simulations. On the other hand preparation and understanding of the waves features shall exist in order to study the variation of it. A simulation of different amplitudes and frequency to compare between their results.

CHAPTER 5

5.1 CONCLUSION

After running different simulations for ANSYS the following conclusions were made :

1) The pressure at the pore throat varies periodically from the mean value with the same excitation frequency as the excitation signal. Such pressure fluctuation allows the trapped oil to pass through the pore throat constriction.

2) The application of seismic waves is able to provide the required differential pressure for oil mobilization. As such, it could be an alternative to chemical flooding in recovering residual oil left behind after secondary recovery.

The vibration effect of the wave do decrease the capillary forces between the water and the oil, thus affecting the mechanism of deforming the initial shape of the oil droplet and help in squeezing it through the pore throat. Having the seismic wave can provide the minimum differential pressure required for the moving the oil blob at areas where water flooding is not providing it.

5.2 RECOMMENDATIONS

Enhancing oil production is an increasing hot topic especially with the increase of oil demand. Motivated by the low oil price occurring nowadays by the time of this project the enhancement of oil production with the lowest possible cost is a rising matter. It was found that various researches were done to improve the oil production through seismic waves based on application since the 1950s. However it was found that only few researches focused on the fundamentals and the understanding of the physics behind the effect caused. Until now, researched can't confirm the main mechanism driving the trapped oil to migrate in a tertiary recovery though seismic waves. Various mechanisms were exploited and explained as an effect but remaining the topic open and appealing for more researches and experiments.

It was found that seismic waves do have a positive effect with respects to the conditions applied. Therefore the proposal would recommend starting the proposed study in experimental design order to have an in-depth understanding and explanation on the mechanisms affecting the capillary forces. Given a positive results and a strong explanation on the phenomenon then the proposal would recommend taking the project further to a 3D experiment to have a better explanation and formulation on how can the seismic waves affects the capillary forces of the trapped oil.

The model was constructed to conduct the simulation with some basic studies and fundamental settings. The model is under development phase in order to patch the correct conditions for trapped oil in ANSYS. It is recommended to keep the development phase until June when some solver calculations can take place. It is recommended as well to start ordering the equipments and tools needed for FYP II lab experiment in order to be in place in time according to the desired timeline

REFERENCES

[1] I.A. Beresnev, and P.A. Johnson, "Elastic-wave stimulation of oil production: A review of methods and results" in *Geophysics*, 59, Los Alamos, Los Alamos National Laboratory, 1994, PP. 1000–1017.

[2] S.R. Pride, E.G., Flekkoy, and O. Aursjo, "Seismic Stimulation for enhanced oil recovery" in *Geophysics*, 73**,** U.S. Department Of Energy, 2008, PP. 23-35

[3] T. Hamida and T.Babadagli, "Effects of ultrasonic waves on the interfacial forces between oil and water " in *Ultrasonic Sonochemistry*, 15, Alberta, University of Alberta, 2008, PP. 274-278

[4] T. Hamida and T. Babadagli "Displacement of oil by different interfacial tension fluids under ultrasonic waves" in *Colloids and Surfaces A: Physicochem. Eng. Aspects*, Alberta, University of Alberta, 2008, PP.176-189

[5] E. Mohammadian, E. Junin, O. Rahmani and A.K. Idris, "Effects of sonication radiation on oil recovery by ultrasonic waves stimulated water flooding" in *Ultrasonics*, 53, Johor, University Teknologi Malaysia, 2012, PP. 607-614

[6] R.V. Westmark, J.F. Brett, D.R. Maloney "Enhanced Oil Recovery with Downhole Vibration Stimulation" in *SPE production and operations symposium conference*, U.S. Department of Energy, 2001.

[7] R.F. DeLaCroix and D.R. Courtright, "System and method for enhanced oil recovery using an in-situ seismic energy generator**",** U.S. Patent 8 113 278 B2,Feb 14, 2012.

[8] Spanos, T.J.T. et al.: "Pressure Pulsing at the Reservoir Scale: A New EOR Approach," in *CIM Conference*, Calgary, Canada, 1999.

[9] B.F. Robertson and D.F. Radcliffe, " Impact of CAD tools on creative problem solving in engineering design ", in *Computer Aided Design*, Vol 41. School of Engineering Education, Purdue University, 2009, PP. 136-146

[10] Hong X. and Wei S. “Using solidworks 2000 software to design three-dimensional modeling for assembled part”.Shangahai, China : Tongji University, 2002.

[11] E. Cengiz and C. E. Imrak “Modeling and Numerical Analysis of the wire strand “ in Journal of Naval science and Engineering, vol.5, No. 1. 2009, PP. 30-38.

[12] D. C. Planchard and M. P. Planchard “ Project 4 : Extrude and Revolve feature “ in *Engineering Design with SolidWorks 2003 : A Step-by-Step Project Based Approach Utilizing 3D Solid Modeling*. SDC Publications.

[13] P. P. Iassonov and I. A. Beresnev “ Mobilization of Entrapped Organic Fluids by Elastic Waves and Vibrations “ in *SPE Journal*, Lowa, Lowa State University, 2009.

[14] M. Chen, L. Rosendahl and T. Condra, “A three-dimensional numerical model of thermoelectric generators in fluid power systems”, *International Journal of Heat and Mass Transfer*, vol. 54, no. 1-3, pp. 345-355, 2011.

[15] H. D. Joshi “ A numerical approach for oil slug mobilization in a capillary tube under absence and presence of external excitations “ Master’s thesis, Faculty of Graduate Studies Research, University of Regina, Regina, Canada, 2013.

[16] CFD-Online. Meshing : Introduction [Online]. Available : http://www.cfd-online.com/Wiki/Meshing

[17] R. Gupta, D. F. Fletcher, and B . S. Haynes. On the cfd modeling of taylor flow in microchannels. Chemical Engineering Science, 64(12):2941-2950, 2009.

[18] P. H. Nelson, “ Pore throats in sandstones, tights stones and shales “. American Association of Petroleum Geologists, USA, vol. 93, pp. 329 – 340, 2009