Numerical simulation of the heat losses through the steam injection in enhanced oil recovery process

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Abstract. In this study, a numerical investigation of the effect of using a new insulation of Yttrium oxide with thermal painting of (5 wt.%) on the heat losses from steam injected in the enhanced oil recovery process. ANSYS Fluent v.16 was used in the simulation. Results were obtained for inlet oil velocity of 5 m/s, temperature of 313 K, and inlet steam velocity of 0.1 m/s, temperature of 373 K. The length of tube is 0.5 m. Pressure through the oil decreases along the distance, while through the steam seems to be unchanged. The insulation does not affect on the pressure distribution. Velocity through the oil decreases along the distance and decreases slightly through the steam. Using the insulation lead to reduce the velocity of oil. Steam temperature decreases through before using the insulation and slightly decrease after using the insulation. Using the insulation leads to make the temperature of steam along the distance greater than the temperature before using the insulation. The pressure through the oil decreases along the distance, while through the steam seems to be unchanged. The insulation does not affect on the pressure distribution. The velocity through the oil decreases along the distance and decreases slightly through the steam by 7.14%. Using the insulation lead to reduce the velocity of oil. Using the insulation leads to make the temperature of steam along the distance greater than the temperature before using the insulation by 9.42%.

Keywords: EOR, heat losses, steam injection, simulation.

1. Introduction
In the past few years, the price of the oil and gas is increases very fast as the demand for the oil and gas is increasing drastically. The usage of the oil and gas in developing countries like India and China are increasing very fast. The major sector that is using oil and gas as the major fuel is the industrial sector followed by the oil and consumption for transportation and domestic usage. More industrial activities that are being carried out these days compared to past days. More oil and gas need to be produced in order to fulfill the demand of the customers [1]. Higher oil and gas price will be the advantage for the oil and gas industries to invest more on this sector in order to get more profit out of their revenues. Thus, the oil and gas industries are looking for new ways to maximize their production and at the same time maximize their profit. One of the main focuses of all the oil and gas industries are on the technique on how to increase the recovery of the oil and gas. Enhance Oil Recovery (EOR) is one of their main focus nowadays in worldwide oil and gas industries. The oil and gas industries’ aim are to extract oil and gas as much as possible. Leaving lesser oil in the subsurface will give them more
profit. Thus EOR studies are one of the important studies that have been growing very rapidly nowadays [2, 3]. A production well means the well type that used to extract gas or oil from subsurface deposits, while, injection well is used to place gas and oil production waste deep underground into formations, the two are combined in Figure 1.

![Figure 1. Injection well and Production well [4]](image_url)

Production of oil can be divided into three main phases: the primary, secondary, and tertiary. The primary oil recovery is rising the hydrocarbons into the roof. While, the secondary oil recovery including utilizing gas and water injection, supplanting the oil and leading it to the roof. The third process of EOR (tertiary) is used to enhance the oil production. EOR can increase the oil production although it accompanied with more expensive to employ on a field. Chemical flooding, gas injection, and thermal recovery are the three main types of EOR [5,6]. Thermal oil recovery process supplies energy (heat) into the reservoir to decrease the oil viscosity. In the thermal oil recovery, the steam is injected to thin the density of oil and increasing the flow rate in the reservoir. The chemical process helps to free trapping of oil inside the reservoir. This process supplies molecules of long-chain called polymers into the reservoir to enhance the water flooding efficiency. The tertiary method includes injecting gas such as natural gas, carbon dioxide, and nitrogen into the reservoir. These gases are mixed or dissolved with the oil to decrease its viscosity and enhancing the oil flow rate [7, 8]. The heat transmission of geothermal wellbore, particularly the transient and static temperature profiles obtained in injection and production wells, as shown in Figure 2.
Figure 2. Wellbore and Geothermal Temperature [8]

Using steam as an injection fluid to increase the oil viscosity in the production to increase the mobility of oil will sound simple but the mechanism that happens in the injection well is quite complex to really measure the properties of the steam that will be in contact with the oil. One of the most important mechanisms that will be take place in this steam injection method is heat transfer in the injection well [9]. Heat transfer process in the wellbore is one of the most complicated issues and none of them have fully understood the mechanism fully. Why we need to know the heat transfer that will be happen in the wellbore? This is the question that will be in most of the people’s mind when they first heard that heat transfer needs to be study thoroughly in steam injection well. Heat transfer will make the fluid to gain or lose its heat which directly will increase or decrease its temperature. Increment or decrement of the fluid temperature will directly affect the energy that going to be transferred to the production fluid. Let’s say all the way from up to bottom to the injection well the injection fluid is losing its heat thus at the point it reaches the production fluid there will not be enough energy to heat up the oil to increase its viscosity. This tells us that we need to change the parameters for injection at the wellhead (temperature, wellhead injection rate). Other problem that can be avoided because of knowing the heat transfer in the wellbore is the failure of cement. Too much of heat can weaken the cement and can break it. Thus, the ultimate aim of this project is to study on the heat transfer and to come out with an outcome that can tell us the heat properties at the different point of injection well depth. In line with this ANSYS software will be used to come out with the end result. Choosing the correct models and inputting the correct field data in ANSYS and quality check it will be the main task during this project. Thus, Modeling of the flow of the fluids and energy in EOR steam injection wells using ANSYS will be the main task in this final year project [10].

2. Problem statement

There is no single model that can elaborate on the fluid flow accurately. Modeling a fluid flow in the wellbore is a very hard activity as the fluid flow and energy will vary all the times depending on other factors like pressure and so on. Thus, fluid flow only can be measured at the surface at the wellhead using the equipment and the fluid flow at the wellhead will not entirely represent the fluid flow in the wellbore. The properties of injection fluid are not the same as the producing fluid as the temperature
increase and pressure increase will be different. When steam is injected in the well there are a lot of mechanisms that will take into place. Those mechanisms capable of changing the properties of steam injected at the wellhead. The characteristics of the fluid that have been injected will differ as the depth of travelling increases. Thus, none of us can really tell what the characteristic of the fluid at any point in the wellbore will be. One of the most difficult parameters to guess is the fluid temperature. The fluid temperature in our case which is steam is very difficult to predict as the process of heat transfer that will be occurring inside the wellbore. Adding heat to the fluid will increase the fluid temperature while losing the fluid heat to the formation will decrease the fluid temperature. Predicting the fluid temperature is one of the crucial things as the temperature can affect the wellbore structure as well as the production.

Many wellbore heat problems exist which involve heat effects is not considered in the subject development. Examples are expansion of gas, heat generated by friction and latent heat effects from phase changes [1]. Often such complications can be handled by proper modification of the solution. In line with that modeling fluid flow using heat transfer technique will give us the picture on the fluid flow. The nature of multiphase flow through the oil wellbore, mechanism of heat transfer between the surrounding and the wellbore lead to make the whole system coupled and difficult to analyze. Thus, many aspects need to be considered in the calculation of heat transfer to get a good result which is near to the real situation. EOR method is become a crucial method for oil and gas industries nowadays thus there will be always studies going on this sector to find out the best technique for the EOR technique. Developing a model in this field will definitely benefits the oil and gas industries.

3. Wellbore heat transfer
During the process of steam injection, there are some changes occur in steam pressure, temperature, and density. These changes because of the heat transport from the hot steam to the cold formation surrounding the wellbore, the flow restriction caused by the friction between the flowing steam and inner tubing wall surface and the hydrostatic change in pressure with changing the depth [10].

Ramey [11] find out an equation of transient heat transfer by conduction for the case of flowing hot fluids through the tubing. Ramey assumed steady-state flow of the hot fluid and the overall-heat transfer coefficient is distinct of profundity. The kinetic energy and friction losses are neglected. Satter [12] developed the analytical solution of Ramey's model and assumed that the overall heat transfer coefficient is dependent of depth. Wilhite [13] presented a well-known method to predict the overall-heat transfer coefficient.

\[
U_{to} = \frac{r_{to}}{r_{ti} h_f} + \frac{r_{to} \ln \frac{r_{to}}{r_{ti}}}{k_{tub}} + \frac{1}{(h_c + h_f)} + \frac{r_{to} \ln \frac{r_{co}}{r_{ci}}}{k_{cas}} + \frac{r_{to} \ln \frac{r_{ch}}{r_{cem}}}{k_{cem}}
\]  

(1)

where

- \(U_{to}\): overall heat transfer coefficient
- \(r_{to}\): outside tubing radius
- \(r_{ci}\): inside casing radius
- \(r_{co}\): outside casing radius
- \(r_{ti}\): inside tubing radius
- \(k_{cas}\): casing material thermal conductivity
- \(k_{tub}\): tubing material thermal conductivity
- \(k_{cem}\): cement material thermal conductivity
- \(h_c\): natural convection heat transfer coefficient
- \(h_f\): film heat transfer coefficient

A partial differential equation were solved numerically by Fontanilla and Aziz [14] with respect to the quality of steam flowed through wellbore. Hasan and Kabir [15] discovered an equation to predict the hot fluid temperature in the wellbore. Livescu et al. [16] developed a wellbore model used for the case of non-isothermal multiphase flow. So, they reported that the density of any fluid has a small change with varying temperature. Bahonar et al. [17] presented a numerical model for the case of semi-
unsteady two-phase flow can be used to predict the heat transfer value from steam to the wellbore formation. Suzuki [18] found out the heat convection and conduction coexist at the interface of chamber. Ito and Suzuki [19] proved that the mechanism of SAGD process heat transfer occurred by heat convection only. Edmunds [20] concluded that the convection heat transfer involves only 5% the heat transferred by conduction.

4. System SAGD drainage
Because SAGD’s fundamental concept is to pass latent heat of steam in to the cold reservoir to decrease the viscosity of oil, steam exhaustion is immediately associated with the growth of steam chamber in creation and oil output. In order to measure the amount of steam flow into the structure, a descriptive and precise SAGD drainage model is required.

5. Models of analytical drainage
Butler et al. [21] previously suggested an analysis method to explain the SAGD drainage method while the steam cabinet has hit the end of the storage tank. The formula is founded on Darcy’s law, the equations of mass balance and the rules of conduction of heat. For this model, two regularly exposed were given: (1) the device traveled at a set velocity usual to the used; (2) only conduction heat transfer occurred in the interface.

The overall amount of runoff is determined according to:

\[ Q = \frac{\sqrt{2Kg\alpha \phi So h}}{mv_s} \]  

(2)

Where :
- \( Q \) is the amount of oil drainage per unit time and per unit well length
- \( K \) is permeability (effective)
- \( \alpha \) is the diffusivity (thermal)
- \( \phi \) is rock porosity
- \( h \) is the vertical height of the reservoir
- \( m \) is dimensionless constant
- \( v_s \) is viscosity of oil at temperature of steam

One big issue with this method is that during processing the measured chamber control curves are always moved away from output. If the lowest portion of the system lies right with same output height, it is impossible for the oil to pass well without effect of gravity against the supply. Another problem is that in horizontal orientation, the chamber appears to stretch towards infinity.

In 1981, Butler and Stephens [22] presented the "TANDRAIN" concept to strengthen the earlier definition. In the lower portion the chamber interface is straight. This presumption helps the oil to float horizontally and deliver far behind the device. Therefore, the irrigation output gets:

\[ Q = \frac{\sqrt{1.5K g \alpha \phi S_o h}}{m v_s} \]  

(3)

Additionally, the updated model incorporated no-flow border, and the steam interface was allowed to extend just halfway between neighboring well pairs.
Reis (1992) [23] built a generalized SAGD-process analytical model. Throughout traditional SAGD method Reis believed that the steam chamber was an inverted triangle. The overhead chamber travels upwards, while the lower portion is well set at production. Under this model, the output of oil per unit long along the horizontal well is:

\[ Q = \frac{\sqrt{2Kg\alpha\theta S_o h}}{m v_s} \]  

(4)

Where \( \alpha \) is a temperature vector without measurements and be equal to 0.4. Reis also provided the steam oil ratio by assuming that the enthalpy of vapor and heat loss to weigh down.

In 2005 Akin [24] provided a more detailed mathematical equation focused on the research of Reis. The oil viscosity had been fully determined by temperature in the previous study. This research considered the effect of asphalt content on oil viscosity, utilizing Werner et al. theory [25] when evaluating fluid compositions:

\[ \ln \left( \frac{\mu(P,T)}{\mu(P_0,T_0)} \right) = c \left( \frac{1}{T} - \frac{1}{T_0} \right) + E \ln \left( \frac{D + P}{D + P_0} \right) \]  

(5)

Where :
- C is the parameter which defines the viscosity variation with temperature.
- P be the pressure in Pa.
- The temperature is T in Kelvin.
- D, E are theoretical parameters which define the viscosity as a function of the pressure.

In SAGD method, Azad and Chalaturnyk [26] assumed that the variance in geo-mechanical effect and saturation of oil. Dividing the length of the chamber of steam into 90 parts. This is due to the slices number is discretionary, selecting a high number raises processing time without any change in precision. In this analysis the slices number was considered to be 90 for simplicity.

At the end of each time phase the oil saturations shift in each slice. This makes the option of specific relative permeability according to oil saturations in the measurement of the oil volume. In addition, the Duncan maximum equilibrium approach [27] was introduced to quantify porosity and increase in permeability with stress field.

6. Numerical modules

Several researchers have commonly used computational modeling to assist them sense the SAGD method. This may be a tool for validating numerical sample by traditionally comparing the results of physical model and may be used to examine the influence of a particular parameter of the reservoir when the physical properties are inadequately calculated. Chow and Butler carried out a computational simulation [28].

The SAGD method, based on experimental data from Chung and Butler [29]. A graphical analysis of black oil in two parts, three-phase and two-component .This was developed and tested for the SAGD process. The findings revealed that the numerical STARS simulator would provide a fair match of the SAGD cycle through the spreading of steam chamber downwards and sideways when the rising steam chamber was not well modelled due to the lack of incorporated physics to simulate Emulsifying water / oil.
To examine the SAGD output in the sands of Athabasca oil in the case of existence of a top water environment, Law and Nasr [30] performed a numerical simulation of fiddle-scale of the SAGD cycle. For assess the SAGD cycle applicability under various reservoir environments as well as gas caps and water zones, a set of field-scale numerical simulation case was analyzed. This work expanded the information acquired from experiments on a laboratory scale to forecast SAGD output on a field scale.

The objectives of this work are to study the heat transfer mechanism for EOR steam injection well, modelling the steam flow in EOR injection well using ANSYS software, analyzing the results from the ANSYS software and to study on the fluid properties (mainly temperature and pressure) that have been changed according to the well depth, and studying the effects of the heat transfer process to the EOR injection wells during steam injection.

7. Results and discussion
The thermos-physical properties of the crude oil taken from the Nasiriyah refinery and for steam are listed in Table 1:

| Fluid  | Property       | Units     | Value  |
|--------|----------------|-----------|--------|
| Crude Oil | Density       | Kg/m³     | 850    |
|         | Specific Heat  | J/kg.K     | 1822   |
|         | Thermal Conductivity | W/m.K     | 0.13   |
|         | Viscosity      | Kg/m.s     | 1.06   |
| Steam  | Density        | Kg/m³     | 0.5542 |
|         | Specific Heat  | J/kg.K     | 2014   |
|         | Thermal Conductivity | W/m.K     | 0.0261 |
|         | Viscosity      | Kg/m.s     | 1.34x10⁻³ |

Inlet oil velocity is assumed to be 5 m/s., temperature of 313 K, and inlet steam velocity is 0.1 m/s, temperature of 373 K. The length of tube is 0.5 m. The insulation used is yttrium oxide nanoparticle with thermal painting (5 wt.%). The thermo-physical properties of the insulation is listed in Table 2.

| Property       | Units     | Value  |
|----------------|-----------|--------|
| Density        | Kg/m³     | 5000   |
| Specific Heat  | J/kg.K     | 440    |
| Thermal conductivity | W/m.K     | 0.3    |

Figures 3 and 4 present the contours of pressure distribution through oil and steam before and after using the insulation, respectively. From this figure, one can see that pressure through the oil decreases along the distance, while through the steam seems to be unchanged [31-38]. The insulation affect slightly on the pressure distribution, as shown in Figure 9.
Figures 5 and 6 present the contours of velocity distribution through oil and steam before and after using the insulation, respectively. From this figure, one can see that velocity through the oil decreases along the distance, and decreases slightly through the steam [39, 40]. Using the insulation lead to reduce the velocity of oil by 7.14%, as shown in Figure 10.

Figures 7 and 8 present the contours of temperature distribution through the layers before and after using the insulation, respectively. From this Figure, one can see that steam temperature decreases through before using the insulation and slightly decrease after using the insulation. This because of the ability of insulation to prevent the heat from escaping through the insulation due to the low value of thermal conductivity for the used insulation. Using the insulation leads to make the temperature of steam along the distance greater than the temperature before using the insulation by 9.42%, this can be shown in Figure 11. These results gave a good criteria to the case of using thermal barrier coating to enhance the steam energy saving [41-57].
Figure 5. Contour of velocity distribution through oil and steam without insulation

Figure 6. Contour of velocity distribution through oil and steam with insulation
Figure 7. Contour of temperature distribution through the layers without insulation

Figure 8. Contour of temperature distribution through the layers with insulation
Figure 9. Pressure distribution through the oil

Figure 10. Velocity distribution through the oil
Figure 11. Temperature distribution through the steam

8. Conclusions
The following conclusion were obtained from the present work:
1. Pressure through the oil decreases along the distance, while through the steam seems to be unchanged.
2. The insulation affects slightly on the pressure distribution.
3. Velocity through the oil decreases along the distance and decreases slightly through the steam.
   Using the insulation lead to reduce the velocity of oil by 7.14%.
4. Using the insulation lead to reduce the velocity of oil. Steam temperature decreases through
   before using the insulation and slightly decrease after using the insulation.
5. Using the insulation leads to make the temperature of steam along the distance greater than the
   temperature before using the insulation by 9.42%.

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