CERTIFICATION OF APPROVAL

On Overall Heat Transfer Coefficient in EOR Injection Wellbore

by

Abdelrahman S. Ibrahim

A project dissertation submitted to the

Petroleum Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfillment of the requirements for the

BACHELOR OF ENGINEERING (Hons)

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Approved by,

(Mohammad Amin Shoushtari)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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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 by unspecified sources or persons.

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Abstract

Heat losses in oil wells can be very significant, especially when comes to EOR Steam injection wells. the loss of thermal energy through the well completion is unavoidable, However , the knowledge of the amount of heat loss is important and can only done if the value of overall heat transfer coefficient is known. This study aims to calculate the overall heat transfer coefficient and analyze the effect of changing completion design and other parameters inside the well to study the effect of different completion and surface components on the overall heat transfer coefficient

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Introduction

1.1. Background of study

Currently EOR becoming more important than ever as the time for easy oil is ending. There are several methods of EOR, one is to introduce thermal energy to the reservoir using hot steam or hot water in order to reduce the viscosity of the crude oil, this is very essential procedures when come to heavy oil reserve especially in Venezuela a where it has one of the biggest oil reserve in the world but most of it is heavy oil. Another method of EOR is CO2 injection; it aims to reduce the density and viscosity of the crude oil as well. However, CO2 is very sensitive to change in temperature and pressure. Thus, we can see the importance of the heat lost in the wellbore.

Therefore, we should know how to calculate the heat losses in the wellbore which will help us improve or build more optimum designs for the wells and the surface facilities. In order to calculate heat lost we must know the overall heat transfer coefficient and have the knowledge of the effect of changing the surface and subsurface parameters on the overall heat transfer coefficient (Uto)

The overall heat coefficient is combination of several coefficients that depends on the method of heat transfer and the pipe configuration. For unburied pipelines, there will be conduction heat lost through the wall and through any insulation or coating material, and convection losses to the environment. There could be also heat losses by radiation. In the wellbore complex mixture of heat losses can occur due to variety of material which heat will flow through. For example the casing, annuals could be filled with liquid or gas and the cementing.

Overall heat transfer coefficient is the sum of all heat losses methods can be calculated using iteration method introduced in several research papers such as: *Over-all heat transfer coefficients in steam and hot water injection wells* By: G. Paul Willhite, *Modeling of Wellbore heat losses in directional wells under changing injection conditions*, By: K.Chiu & S. C. Thakur. These iteration procedures will give better and faster result if it was built in computer program.

1.2. Problem statement

Heat lost in EOR injection wells is very significant, thus, studying the effect of surface and subsurface parameters to help designing most optimum injection conditions.

1.2.1. Problem Identification

Review of calculation methods for overall heat transfer coefficient showed that it uses the iteration of group of complicated functions that is require very long time if it is to be solved manually in order to get accurate result or can't be solved in some cases. And the effect of each input parameters couldn't not be seen clearly.

1.2.2. Significant of project

The study aims to find comprehensive method to solve the overall heat transfer coefficient models that uses complex iteration and analyze the effect of surface and subsurface parameters on the overall heat transfer coefficient (Uto)

1.3. Objective

1. To obtain the most comprehensive set of functions to calculate the overall heat transfer coefficient (Uto) in the wellbore.

2. To introduce new method of calculating the overall heat transfer coefficient in easier, more accurate and faster way. In order to save the time and produce more accurate results (computer program)
3. Use iteration techniques to obtain the right combination of temperature of the inside cementing (T_{ci}) and overall heat transfer coefficient (U_{to}) .
4. Analyze the effect of different parameters on the heat lost in the EOR injection wells, helping in designing the most efficient injection system

1.4. Scope of Study

The research will involve in the understanding of heat transfer. The study in this project contains two main parts:

1. To identify the best model to calculate the overall hear transfer confident as one component of the calculation of the heat loss in the wellbore.
2. Developing the method of solving this model.

1.5. Relevancy of the Study

This project will focus on the topic of heat transfer in the wellbore. This topic is related to the EOR projects design especially injection wells of steam and hot water as well as petroleum production optimization. The project required knowledge of heat transfer and programming in order to finish this research.

1.6. Feasibility of the project within the scope and time frame

The project will start with literature reviews involve reading text books papers in order to have better understanding on the topic of heat transfer and heat transfer coefficient as it involve the learning of programming software. The result will have good impact on heat loss prediction through the wellbore.

2. CHAPTER 2

THEORY & LITERATURE REVIEW

2.1. Heat transfer mechanism:

2.1.1. **Conduction** is the transfer of energy from more energetic particles of substance to the adjacent less energetic ones as result of interactions between the particles. Conduction can take place in solids, liquids or gases. In the wellbore the conduction occurs in the tubing wall, casing wall and the cement. Fouriers discovered that the heat transferred through body is directly proportional to the temperature gradient in the medium. K represents this proportional factor.

$$Q = KA\,(T_1 - T_2) / \Delta x$$

Where:

Q : heat flow ,Btu/hr

K : thermal conductivity, Btu/hr ft°F

T : temperature°F

ΔX : distance ft

Integration of the previous formula in terms of Q will give us the heat losses by conduction in the tubing wall, casing wall and the cement:

- Tubing: $Q = [2\pi K_{tub} (T_{ti} - T_{to}) \Delta L] / [\ln(r_{to} / r_{ti})]$
- Casing: $Q = [2\pi K_{cas} (T_{ci} - T_{co}) \Delta L] / [\ln(r_{co} / r_{ci})]$

- Cementing: $Q = [2\pi K_{cem} (T_{co} - T_h) \Delta L] / [\ln(r_h / r_{co})]$

2.1.2. **Radiation** is energy emitted by matter in the form of electromagnetic waves as a result of the changes in electronic of the changes in electronic configurations of the atoms or molecules. In the wellbore radiation occur in the annuals between the tubing and the casing could be represented by the following formula:

$$Q_r = 2\pi r_{to} h_r (T_{to} - T_{ci}) \Delta L$$

Where:

h_r: heat transfer coefficient based or radiation, Btu/hr sq ft°F

2.1.3. **Convection** is the mode of energy transfer between a solid surface and adjacent liquid or gas that is in motion and it involves the combined effect of conduction and fluid motion. In the wellbore study literature showed that the difficulties in calculating heat transfer due to the natural convection that occur in the annuals the reason behind that is most of the work done in natural convection was based on work two vertical plates and very little work was done on radial form. The heat transfer between the inside casing and the outside tubing can be represented in the following formula:

$$Q = [2\pi K_{hc} (T_{ci} - T_{to}) \Delta L] / [\ln(r_{ci} / r_{to})]$$

Where:

K_{hc} : equivalent thermal conductivity of the annular fluid with natural convection effect evaluated and average pressure and temperature of the annular , Btu/hr ft°F

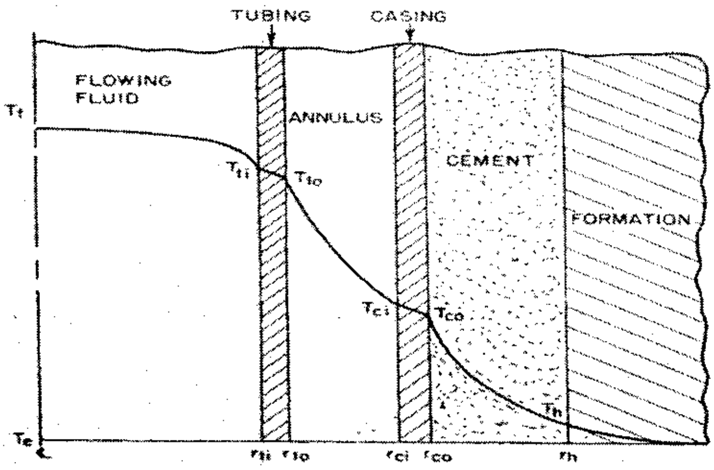


Figure 2.1: An illustration of heat losses in different components of the wellbore.

2.2. Heat loss and overall heat transfer coefficient:

Several authors did study the well temperature in injection and production wells but was always limited to long prediction period and no model was developed to predict heat losses in short time. The first to present a model that is applicable to variety of heat losses condition was Ramey.

Ramey has published a model that includes equations could be programmed to calculate heat losses and wellbore temperature. The paper was the first to introduce the term overall heat transfer coefficient comprising both transient heat resistance in the formation and near wellbore heat resistance. However, in order to simplify the calculation Ramey model had made the overall heat transfer coefficient independent of depth and didn't take into account the change in fluid properties with the change of depth and temperature. Ramey's model assumed steady state of single phase either incompressible hot fluid or ideal gas.

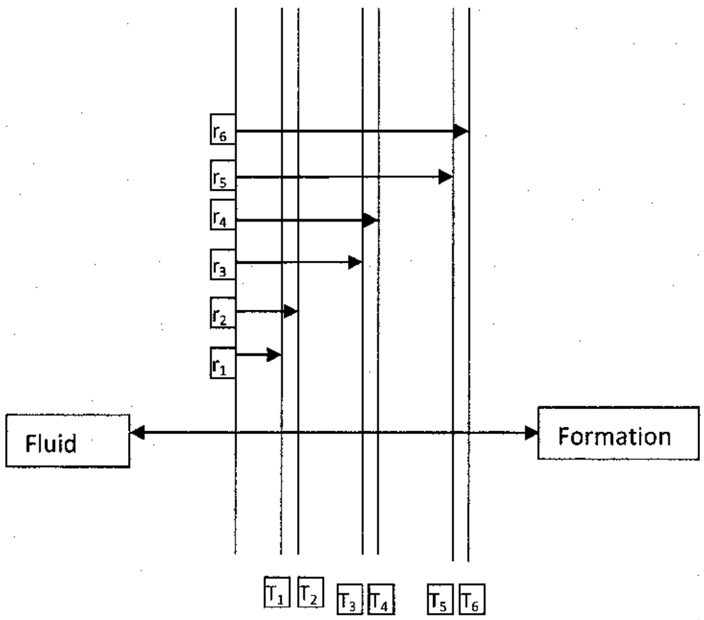
Satter (1965) improved Ramey's model by including the effect of condensation of the steam in steam injection wells this could be considered as the first model that study two phase flow, in the same study Satter presented the effect of well depth in the overall heat transfer coefficient. However, the effect of kinetic energy was neglected in this model too.

Even though this model did take into consideration the change of overall heat transfer coefficient with the depth it did assume the geothermal gradient to be constant and any variation in the thermal properties of the earth was neglected. In 1967 Willhite presented a method for determining the overall heat transfer coefficient and showed the combination of different heat transfer methods included in the model.

Holst and Flock (1966) did further improvement on Ramey's model by circumventing the restriction of constant wellbore heat transfer coefficient and temperature-independent fluid properties. Using trial and error solution of fluid temperature and the wellbore heat transfer coefficient, relationship were obtained for steamy quality and heat loss as function of depth. In order to obtain the mathematical model the system was divided into three systems:

1. The Fluid
2. The Wellbore
3. The formation

The heat flux across the system boundaries served as parameters inter-relating the three systems. The model did include the heat lost due kinetic energy and friction, the effect was relatively minor. However the quality and the temperature profile were greatly affected by this modification. The great significant of this model because it includes the pressure drop due to friction which could be great contributor to the overall pressure drop especially in injection wells where the fluids is injected in high velocity which will lead to great pressure loss due to friction



$$U_{to} = \frac{1}{C_3}\left(\frac{1}{C_3 - C_4\,(T_2 - T_3)(T_2^2 - T_3^2) + C_3 * C_5 K_C + 1}\right)$$

Where:

U_{to} : Overall heat transfer coefficient, Btu/hr sq ft°F

C : Heat capacity

The model doesn't take into account the change in thermal properties of the formation with change in depth and it assumes the use of packer and having constant pressure air only in the annuals

Chiu (1991) introduced new model that can calculate the heat losses taking the change in injection or production rate into account, where all the previous models used to assume constant production/injection rate, in order to do that Chiu presented a new empirical expression for the transient heat loss function. Its valid for all times and gives result closer to the exact solution than the more commonly used for long time asymptotic solution

$$f(t) = 0.982\ln[1 + 1.81\frac{\sqrt{\propto t}}{r_h}]$$

Where :

$f(t)$: *Transit heat loss function*

$\propto$: thermal diffusivity of the formation

t : time, days

r_h : radius of the hole ,ft

The model claims to be capable of calculating heat losses in directional wells, where by the well is divided into segments which their inclination values can vary with depth

Alves, Alhanatle and Shoham (1992) presented comprehensive model to calculate the heat losses in the wellbore in any inclination angle and two phase flow based on Ramey's model and Begs and Brill model for two phase flow in pipeline. Their model was unified and can be applied to injection as well as producing wells. This model could be reduced to Ramey's with the use of proper assumptions and simplifications.

In calculating the overall heat transfer coefficient Fontanilla and Aziz has published a paper to predict the bottom hole conditions for wet steam injection wells. The paper was focusing in the calculation of heat losses in the wellbore incorporation with two phase flow models such as Beggs and Brill or Yamazaki and Yamaguchi. However, this paper did include comprehensive equations to calculate the overall heat transfer coefficient using iteration procedures that could be programmed in computer.

The General formula for the overall heat transfer coefficient:

$$dq/dz = 2\pi \, rto \, Uto \, (Tf - Th)$$

In order to calculate U_{to} assumption must be made for the heat loss to the surrounding along the well as well as the value of the inside cementing temperature assumed to equal the earth temperature. The actual result could be obtained using iteration procedures

3. CHAPTER 3

METHODOLOGY / PROJECT WORK

3.1. Research Methodology

The approach in this project is basically divided into three major stages which are literature review, the programming hence once results are achieved a detailed evaluation is to be done and results are to be discussed. The flow of my project would be as follows:

3.2. Project Work

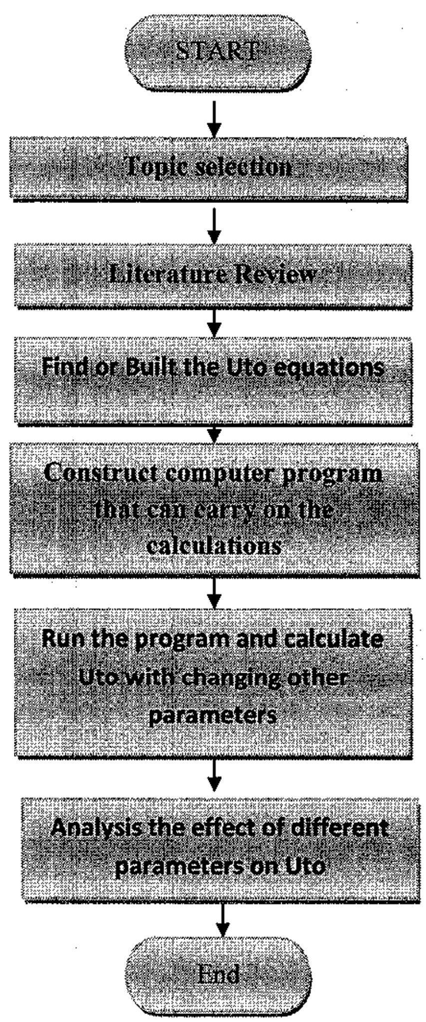


Figure 3.1 : illustrate the flow chart of the project

Steps	Activity
Title Selection	Selection of the most appropriate final year project title.
Literature review	The performing of initial ground work in obtaining information regarding the project and its elements like fundamental theories and concepts, hardware, software and other verifications. Also included critical literature survey to enhance knowledge about advances and previous studies regarding overall heat transfer coefficient and heat lost in the wellbore, among others. Initial tools/equipments that are required were identified.
Software used	Software to conduct the calculations is chosen(Mathematica 8)
Find or Built the Uto equations	There are several models to calculate the overall heat transfer coefficient such as Ramey's , Whillhite's or Fontanilla's models. From the literature review Fontanilla's model was chosen to be used in this study.
Construct computer program that can carry on the calculations	The selection of the software to be used in order to calculate the overall heat transfer coefficient is first step in constructing the program itself , this is because calculating the overall heat transfer coefficient can only done through complex iteration equations
Run the program and calculate Uto with changing other parameters	After constructing the program , it's been tested with same field data and then some parameters will change to test its effect on the value of the overall heat transfer coefficient and result is plotted in graphs to ease the access and analysis
Analysis the effect of changing different parameters on Uto	Analysis of the graphs. possible explanation and conclusion drowns for each parameter effect

Writing the report	Compilation of all research findings, literature reviews, experimental works and outcomes into a final report.

Table 3.2: Elaboration on the Key Milestones

3.3. The program

The model of calculating overall heat transfer coefficient is already been obtained from some of the references which is Fontanilla model. A modification has been adopted.

3.3.1. The modification:

Fontanilla model input the thermo physical properties of the annuals fluid before the calculation starts. In this study air is been assumed to be the annuals fluid for all time and the thermo physical properties all have been changed to be function of air temperature only.

$$\rho\,(\text{density of air}) = 360.77819 * T^{-1}$$

$$\nu\,(\text{KinematicViscosity}) = -1.1555 * 10^{-14} * T^{3} + 9.5728 * 10^{-11} * T^{2} + 3.7604 * 10^{-8} * T - 3.4484 * 10^{-6}$$

$$\alpha(\text{ThermalDiffusivity}) = 9.1018 * 10^{-11} T^{2} + 8.8197 * 10^{-8} * T - 1.0654 * 10^{-5}$$

The rest of other parameters such as Pr (Prandtl number) , Gr (Grashof number) are based on this parameters, by doing this modification the input parameters have been reduced.

3.3.2. The remainders input parameters needed for the program to run are:

Grad: Geothermal gradient

D: Depth

Tf: Temperature of the fluid

Rins: radius insulation

Rto: radius outside tubing

Rco: radius outside casing

Rci: radius inside casing

Rh: radius of the hole

Kins: thermal conductivity of insulation

Kcem: thermal conductivity of cementing

Ke: thermal conductivity of earth

eins: emissivity insulation

eci: emissivity inside cementing

g: acceleration due to gravity $4.17*\mathbf{10^8}$

∝: Stefan-Boltzman constant $0.1714*\mathbf{10^8}$

T: time of injection

б: Thermal diffusivity of earth

Beside these impute users required to assume arbitrary value for dq/dz and made the assumption of making Temperature of the inside casing is to be equal to the earth temperature at first stage. The actual results will be obtained later through the iteration procedures.

3.3.3. The steps and formulas used in this model are :

1) Assume the value of Tci to equal Te and arbitrary value of dq/dz.

2) T_{ins} (Temperature of insulation) $= T_{to} - \frac{\frac{dq}{dz} In(\frac{r_{ins}}{r_{to}})}{2\pi Kins}$

3) h_r (Heat transfer coefficient radiation) $= \frac{(Tains + Taci)[(Tain s)^2 + (Tac i^2)]\sigma}{\frac{1}{\epsilon ins} + \frac{rins}{rci}[\frac{1}{\epsilon ci} - 1]}$

4) h_c (Heat transfer coefficient convection) $= \frac{Khc}{rins\ In(\frac{rci}{rins})}$

5) U_{to} (Overall heat transfer coefficient) $= [\frac{rto\ In\left(\frac{rins}{rto}\right)}{Kins} + \frac{rto}{rins\ (hc + hr)} + \frac{rto\ In\left(\frac{rh}{rco}\right)}{Kcem}]^{-1}$

6) T_h (Hole temperature) $= \frac{rto\ Uto\ f(t)\ Tf + Ke\ Te}{rto\ Uto\ f(t) + Ke}$

7) $T_{ci(new)}$ (Inside casing temperature) $= Th + \frac{rto\ Uto\ \ln\frac{rh}{rco}}{Kcem}\ (Tto - Th)$

8) If $|new\ T_{ci} - old\ T_{ci}| < 1$ F go step 9 else go to step 13

9) $dq/dz = 2\pi\ r_{to}\ U_{to}\ (T_f - T_h)$

10) $T_h = \frac{Tci(new) * Kcem - rto * Uto * \ln\frac{rh}{rco} * Tto}{Kcem - rto * Uto * \ln\frac{rh}{rco}}$

11) $T_{ci(new)} = Th + \frac{rto\ Uto\ \ln\frac{rh}{rco}}{Kcem}\ (Tto - Th)$

12) Use the new values of Tci and dq/dz and repeat from step 3 .

13) Extract the value of Uto.

3.3.4. Flow chart of the program :

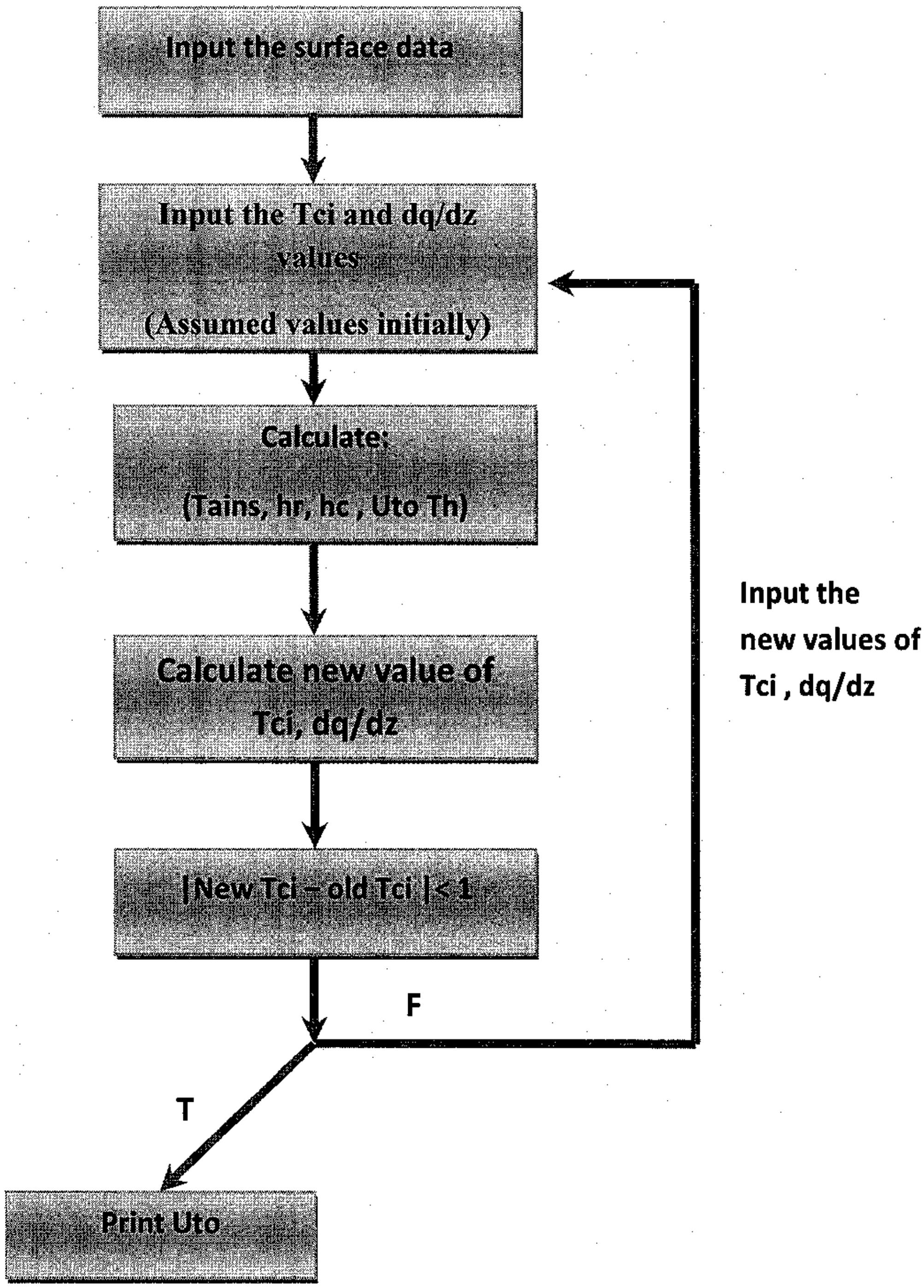


Figure 3.2 : illustrate the flow chart of the program.

3.4. Tools required

One of the following programming software will be used in making the program to estimate the overall heat transfer coefficient or both will be used simultaneously

3.4.1. Mathematica software:

Is a computational software program used in scientific, engineering, and mathematical fields and other areas of technical computing. It was conceived by Stephen Wolfram and is developed byWolfram Research of Champaign, Illino

3.4.2. Matlab:

Is a numerical computing environment andfourth-generation programming language. Developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access tosymbolic computing capabilities. An additional package, Simulink, adds graphical multi-domain simulation and Model-Based Design for dynamicand embedded systems.

3.5. Gantt Chart and Key Milestone

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Refining the model & learning of Mathematica software	■	■	■	■	■	■	■	Mid Semester Break								
2	Submission of Progress Report									☆							
3	Coding of Model in Mathematica software									■	■	■	■	■			
4	Pre EDX												☆				
5	Submission of Draft Report													☆			
6	Submission of Dissertation (softbound)														☆		
7	Submission of Technical Paper														☆		
8	Oral Presentation															☆	
9	Submission of Dissertation (hard bound)																

Table 3.5: Illustrate Gantt Chart for the second semester project implementation.

4. Chapter 4

Results and discussion

This chapter will discuss the effect of several different parameters on the overall heat transfer coefficient:

4.1. The effect of insulation thickness

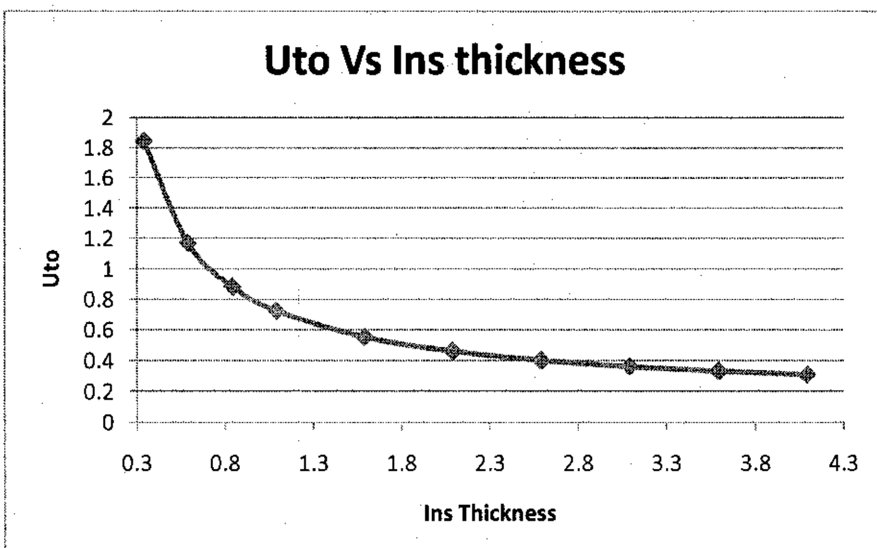


Figure 4.1.1: shows the overall heat transfer coefficient Vs the insulation thickness

Study on the effect of the insulation thickness showed that the increase of the insulation thickness is significant and will reduce overall heat transfer coefficient but until certain extend only. The decrease of overall heat transfer coefficient with the increase of insulation is rapid with thin insulation. However as we increase the insulation thickness the effect on overall heat transfer becomes much smaller.

It's known that adding more insulation to a wall will always decrease heat transfer. The thicker the insulation the less heat lost. This happened because the heat transfer area remains constant at all time.

Adding insulation in cylindrical or spherical shape, however, is different matter. The increase of insulation will increase the coactions resistance but at the same time will decrease the resistance of the convection resistance because the outer surface area for the convection increased

Considering cylindrical pipe in figure (3) where:

Rot : the outer radius of the pipe

Tot : the temperature of the outer pipe surface

Rins : the outer radius of the insulation

Tout : temperature of the surrounding

K : thermal conductivity of the insulation

Q : the heat lost .

h : convection heat transfer coefficient .

$$Q=\frac{Tot-Tout}{\frac{\ln {Rins}/{Rot}}{2\pi LK}+\frac{1}{h(2\pi\, Rins\ L)}}$$

Plotting the variation of Q versus the outer radius of the insulation shown in figure () , the value of Rins with the maximum Q can be determined dQ/dRins . Solving the differentiation for Rins yields the Critical radius of insulation to be:

$$Rcr = \frac{K}{h}$$

Rcr : Crtical radius

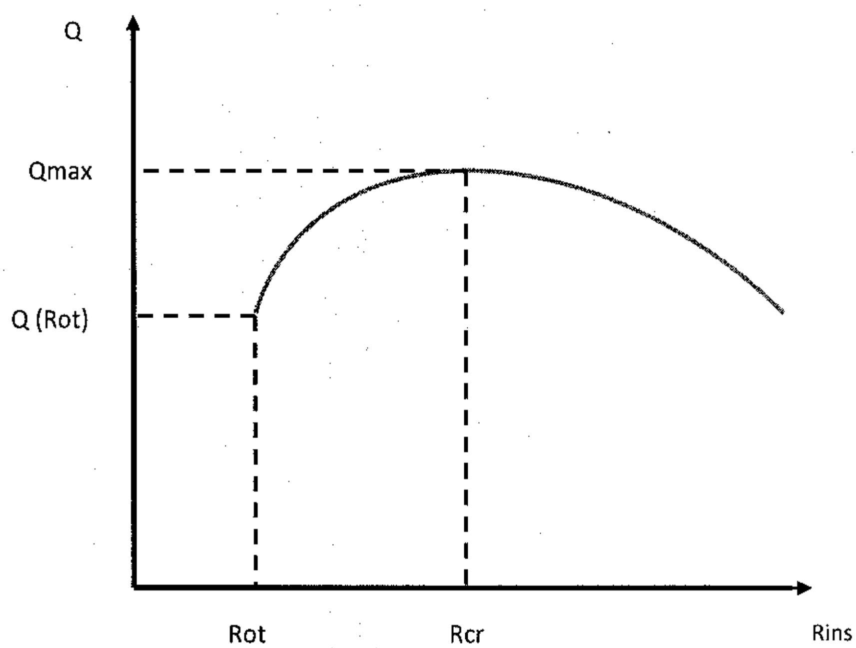


Figure 4.1.2: illustrate the relationship between insulation thickness and heat lost

Knowing the effect of insulation thickness on the overall heat transfer coefficient could help designing the most optimum insulation thickness in the wellbore, because it will be known at some point the increasing of the insulation thickness will not be economical, even though before reaching the critical radius, the cost of increasing the insulation thickness could be higher than the rate of return as it seen the effect will decrease rapidly at some point.

4.2. The Effect of casing size with different formation thermal conductivities

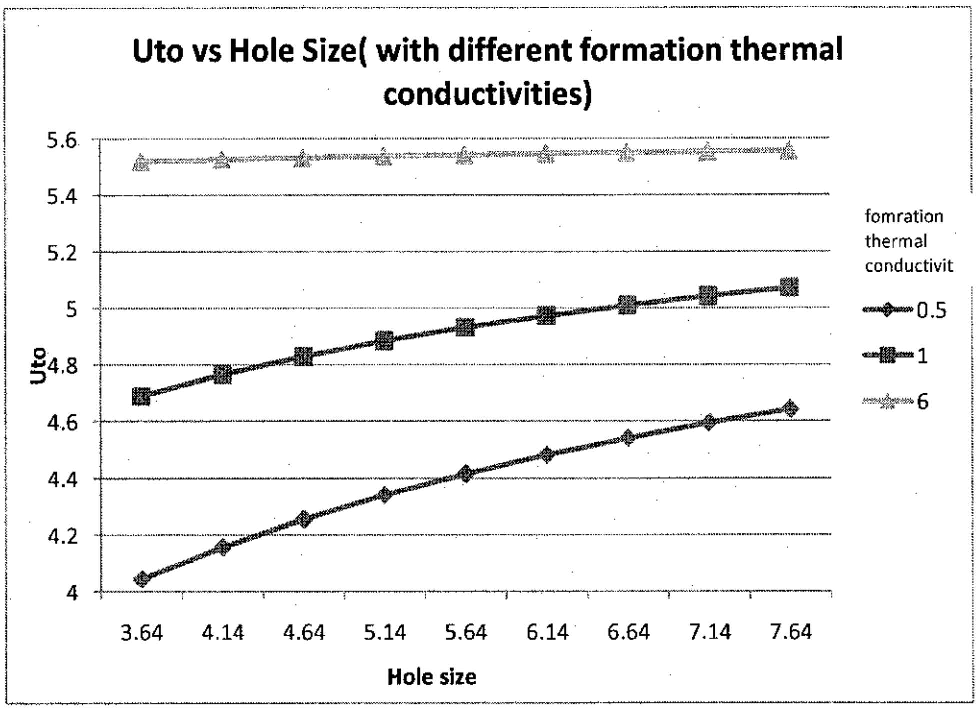


Figure 4.2: illustrate the relationship between overall heat transfer coefficient and hole size at different formations

The graph in figure (4.2) shows the behavior of overall heat transfer coefficient (Uto) with changing the casing size for different formations with different thermal conductivity. It's seen that the increase in the hole size will increase the overall heat transfer coefficient (heat lost), this is expected behavior as the radiation heat lost is directly proportional to the area in between the casing and tubing.

$$Q_{rad} = h_r A (T_s - T_{sur})$$

Q_{rad} : radiation heat loss

h_r : radiation heat transfer coefficient

A : Area of the surface in which the heat loss occurs

T_s : Temperature of the surface

T_{sur} : Temperature of the surrounding

Another factor for increasing the heat losses with the increase of the hole size is the relationship between the annuls thickness and convection heat losses is directional mean the increase of the annuls thickness (increase of casing size) will result in more convection heat losses.

$$Q_{con} = h_{con} A (T_s - T_{sur})$$

Q_{rad} : convection heat loss

h_r : convection heat transfer coefficient

Besides the fact that increasing the casing size will cause more heat losses, increasing the casing size means increasing the cost of the casing as well as it's require bigger hole size which will require bigger drilling bit and higher cost. Therefore, in steam injection wells or hot water injection wells the casing size should remain as its minimum.

Another observation could be seen in the figure is the behavior of the overall heat transfer coefficient with changing in casing size in different formations. The effect of casing size is higher for formations with low thermal conductivity and its almost has no effect with formation with high thermal conductivity.

Therefore, casing size effect should be taken more into consideration when designing steam injection or hot water injection well in low thermal conductivity formation.

4.3. <u>The effect of hole size</u>

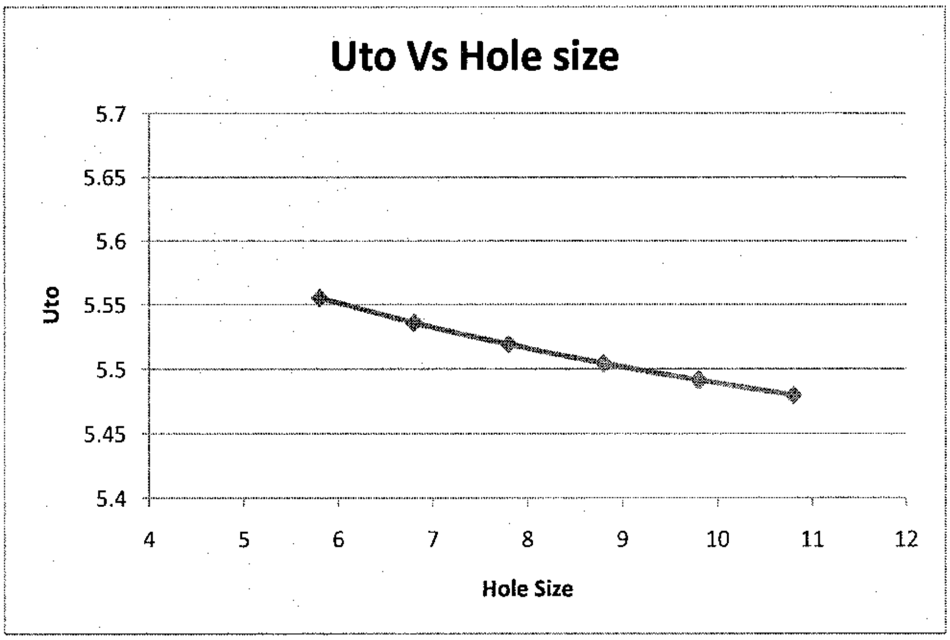


Figure 4.3: illustrate the relationship between overall heat transfer coefficient (Uto) and the hole size

The figure (4.3) shows the behavior of overall heat transfer coefficient with increasing of the hole size while keeping the casing and tubing size fixed. The figure shows when increasing the hole size a decrease in the overall heat transfer coefficient and therefore decrease in heat lost will happened.

The negative effect of the hole size on the overall heat transfer coefficient is due the thermal conductivity of the cement used in making this model is much less than the thermal conductivity of the formation (thermal conductivity of cement < 20% thermal conductivity of formation), knowing this figures has been taken from several references such as K. Chiu paper on the modeling of heat lost in directional wells and others.

Even though, the increase of the hole size will reduce the overall heat transfer coefficient, the reduction of the heat lost is not very significant and the effect is minor. While increasing the whole size will require bigger drilling bit and more cementing which will increase the cost of the well.

The energy and money saved by increasing the wellbore size will not cover the cost of drilling and completing such a well. Besides the casing might not stand the pressure induced by thick cement layer and could collapse. Therefore increasing the wellbore size in steam or hot water injection well is not justified.

4.4. The effect of injection time :

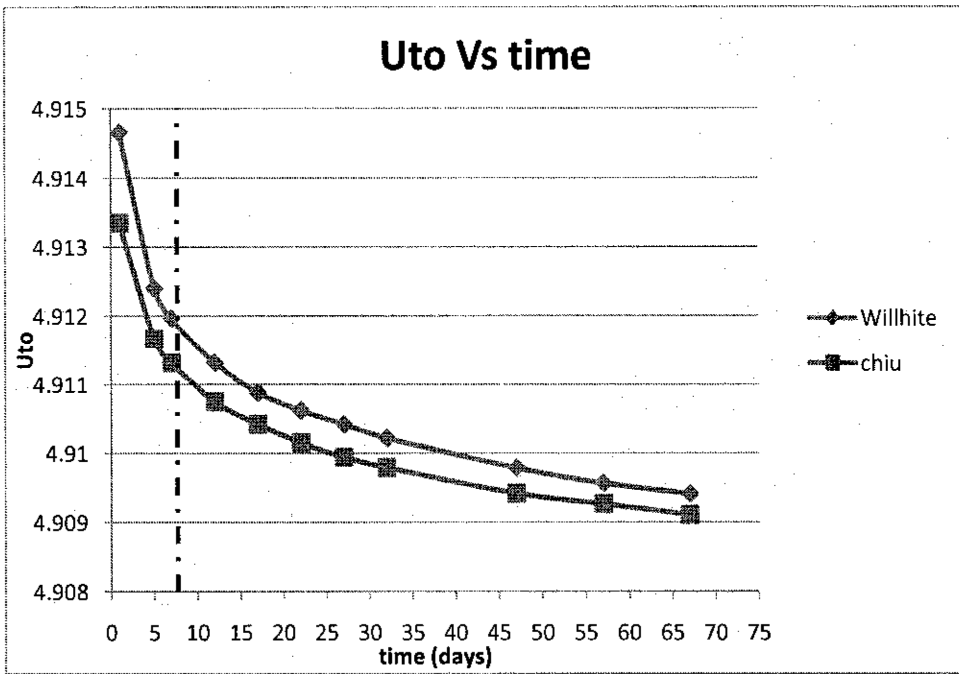


Figure 4.4: illustrate the relationship between time and overall heat transfer coefficient

The figure (4.4) shows the behavior of overall heat transfer coefficient with changing time. It's clearly shown that the overall heat transfer coefficient drops rapidly in the very first few days, and this drop will decrease as time passes.

The reason why the overall heat transfer behave in such away is that in the first few days the heat losses is in unsteady sate and the heat transfer didn't reach the boundary condition, after few days the heat transfer will reach study state and the overall heat transfer will drop slowly as it's clearly shown in the figure ()

The significant of this figure or this relationship is to not relay on the data that is collected at first few days of the injection as the heat transfer didn't reach steady state and the data will not represent the heat lost for the later stage of the injection, Ramey suggested that the heat transfer will reach study state after 7 days of injection, this number agree with our graph to certain extend where we can see after the seventh day the graph slop will drop.

F(t) is transit heat conduction function, Enters into wellbore heat loss calculation because heat flow in the surrounding formations varies with time

The two graph in the figure represent two different models of time function f(t)

4.4.1. Chiu :

$$f(t) = 0.982 * \text{Log}[1 + \frac{1.81 * \sqrt{\alpha * t}}{\text{Rh}}]$$

where :

Rh: hole radius

t : time

∝: thermal diffusivity of the formation

4.4.2. Whillhite :

$$f(t) = \text{Log}\left[\frac{2 * \sqrt{\alpha * t}}{\text{Rh}}\right] - 0.29$$

4.5. The effect of injection fluid temperature at the surface :

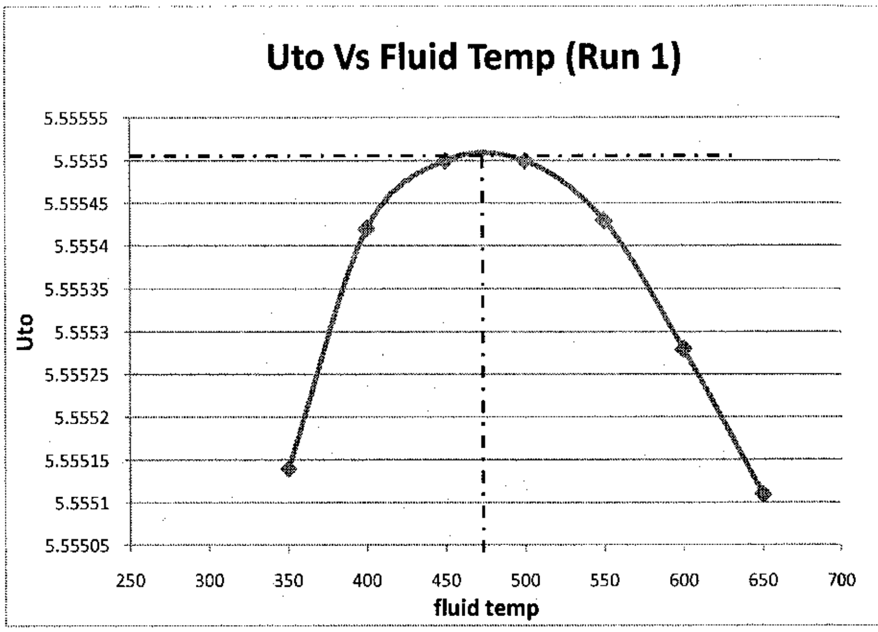


Figure 4.5.1: illustrate the relationship between injection fluid temperature and overall heat transfer coefficient (Run1).

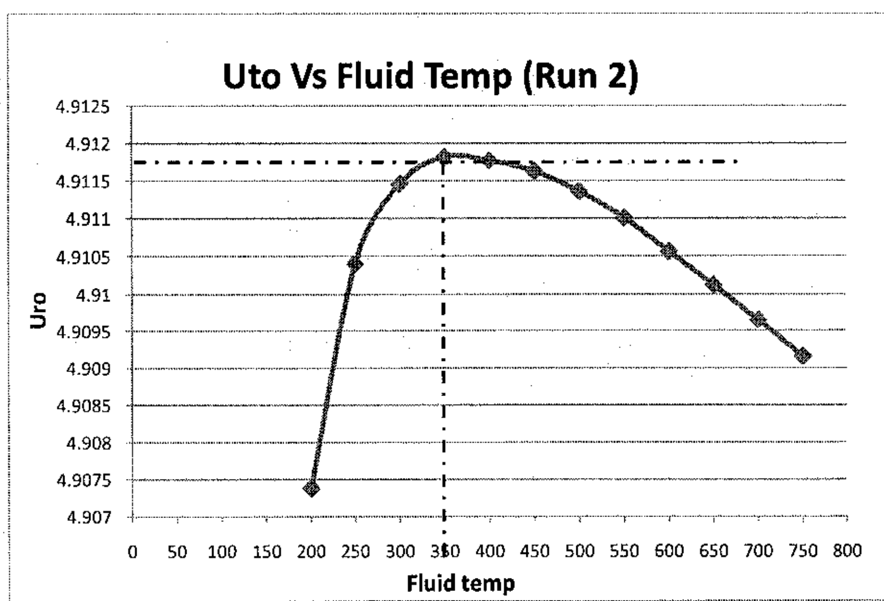


Figure 4.5.2: illustrate the relationship between injection fluid temperature and overall heat transfer coefficient (Run 2).

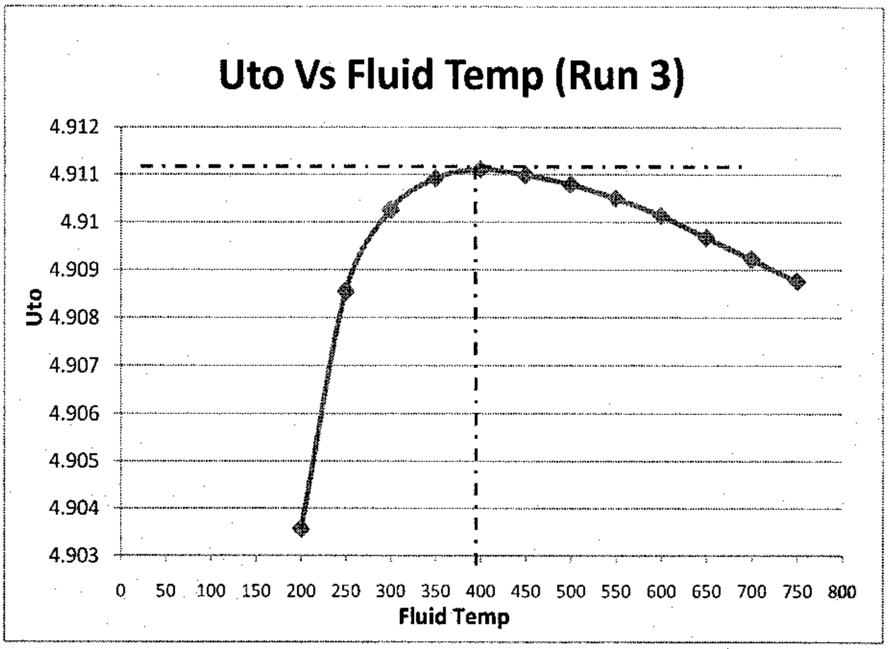


Figure 4.5.3 : illustrate the relationship between injection fluid temperature and overall heat transfer coefficient (Run 3).

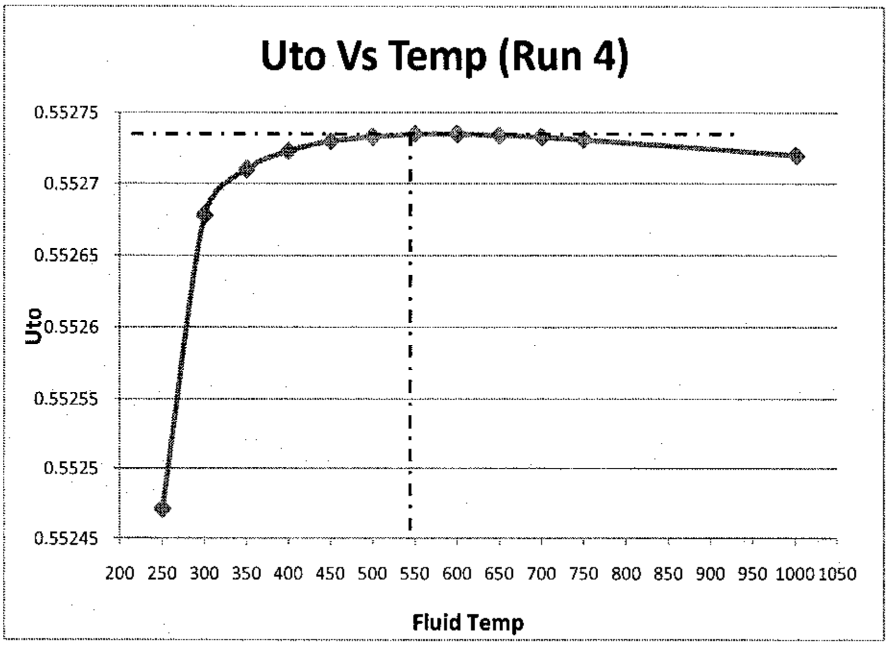


Figure 4.5.4 : illustrate the relationship between injection fluid temperature and overall heat transfer coefficient (Run 4).

The figures 4.5.1-4.5.4, shows the behavior of overall heat transfer coefficient with the changing the fluid injection temperature at the surfaces. The overall heat transfer coefficient curve exhibit a peak at some point,

several runs for overall heat transfer coefficient with respect to injection fluid temperature at the surface has been conducted with changing of some parameters such as depth and well configuration to know if the shape of the curve is caused by the temperature of the injection fluid or some other parameters could effected it.

Looking at Run 1 to 4 they all exhibit the same shape with slight different in the slop, however, the maximum overall heat transfer coefficient occurs at different temperatures

Run	Temperature
1	450-500
2	325-375
3	375-425
4	500-600

Table 4.1: illustrate peak heat loss temperature for each run

Knowing the surface temperature that causes the maximum heat lost in the well is very important. As it could help avoiding injection at that particular temperature if possible. Either injects fluid at higher or lower temperature. However, there are other parameters to be considered such the desired fluid temperature in the wellbore or the cost of heating the steam or the water to very high temperature and whether it's feasible or not.

This is just one factor the engineer should consider while designing the injection well, but sometimes injection fluid at the maximum heat loss temperature is the best option when considering other factors such the ones mentioned above.

4.6. The effect of depth:

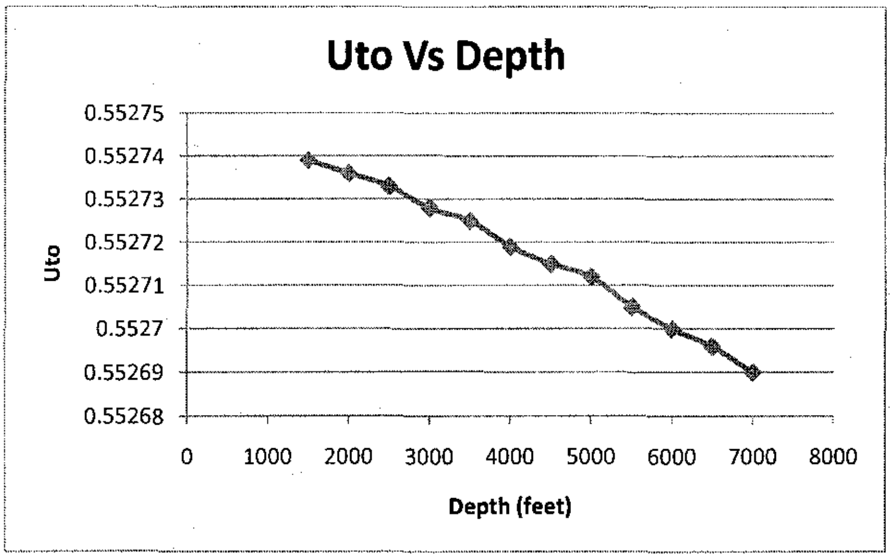


Figure 4.6: illustrate the relationship between depth of the well and overall heat transfer coefficient.

Figure (4.6) shows the behavior of overall heat transfer coefficient with respect to well depth. The curve shows decrease in the value of the overall heat transfer coefficient as we go deeper.

The theory behind this is by going deeper the temperature of the formation around the wellbore will increase and the temperature of the injection fluid will decrease. Therefore, the temperature difference that responsible for heat flow from the injected fluid to the formation is reduced which will cause decrease in the overall heat transfer coefficient and heat loss.

The significant of this curve or the usefulness is that can indicate to which extend or depth insulation is needed, it's known that the cost of insulation is high and any saving in the insulation cost is very appreciated. Therefore knowing at what depth the heat lost or the overall heat transfer coefficient is insignificant is important.

5. Chapter 5
Conclusions and Recommendations

5.1. Conclusion :

As results of analysis of overall heat transfer coefficient (Uto) the following conclusions could be drawn:

5.1.1. Increasing the insulation thickness in the wellbore will reduce the overall heat transfer coefficient as well as the heat lost in the well. However, the thickness reach a critical point where increasing the thickness will cause more heat loss.

5.1.2. The increase of casing size with constant tubing size will result in increase in overall heat transfer coefficient. However this effect is function of the formation thermal conductivity where casing thickness has maximum effect in low thermal conductivity formation and very little effect on the formation with high thermal conductivity.

5.1.3. Increasing the hole size will result in decrease of overall heat transfer coefficient, though this approach to reduce heat lost is not economical because of the high cost of drilling bigger hole and the reduction in heat lost not very big.

5.1.4. The longer time for injection fluid or producing hot fluids will result in less heat loss and smaller value of overall heat transfer coefficient.

5.1.4.1. The changing of injection fluid temperature has curve with maximum point at certain temperature for different conditions. Further study could be done to find out the theory casing these phenomena.

5.1.5. Increasing the depth will result in less heat loss as the temperature of the formation rise with depth.

5.2. Recommendation

6.1.1. In this study only one model of calculation overall heat transfer coefficient was utilized (Fontanilla). For better and more comprehensive results other models should be used and comparative of the results could be done to check if all behave in the same manner when changing particular parameter.

6.1.2. The study was based on real field data, however, in the sensitivity analysis most of the data were arbitrary numbers to check the effect of each parameter only. The study could be further improved if all the analysis were based on real industrial data such as casing diameter or hole size.

6.1.3. The effect of injection fluid temperature at the surface exhibit an interesting curve with peak point where at particular temperature the heat lost will be maximized. Further study could be conducted to investigate the theory behind this phenomenon.

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