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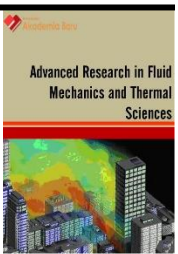

Numerical Simulation of Fluid Flow and Heat Transfer in Wellbore

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ABSTRACT

Accurate heat transfer modelling can contribute significantly in that realm. Earth temperature generally increases with depth. Thus, as the hot fluid from bottom hole rises up the wellbore, its temperature is higher than the surrounding Earth temperature which causes it to lose heat to the surroundings. When the flow rate of the fluid increases, more of the hotter fluid from the bottom displaces the colder fluid in the wellbore at any given point and therefore the temperature increases. ANSYS Fluent was used to simulate the fluid flow and heat transfer in wellbore of crude oil flowing upward in the tubing and gas (air) injected through holes to increase the wellbore production. Results show that the crude oil velocity seems to be decreased downstream throughout the tubing. The pressure seems to be reduced throughout the tubing because of losses cause the friction between crude oil and the tubing wall. Eddy viscosity of crude oil be larger at the entering and fluctuated between decrease and increase throughout the tubing. Turbulent eddy dissipation be large only at the entering (bottom) and gradually reduced along the tubing till it minimum value at the exit (top). The turbulent kinetic energy be larger be larger at the entering (bottom) and minimized throughout the tubing till it be in a lower value at the exit (top). Crude oil temperature was decreased along the tubing centerline and the minimum value at the tubing exit (top). The heat transfer coefficient value be minimum at the entering and increased suddenly through the (0.1) of the total tubing length.

1. Introduction

One of the wonders of modern science is the ability to discover or create energy intensive fuels. The on-going battle between the depleting energy resources and the initiatives to find new ones has given birth to a need of a greater workforce striving towards this important task. According to recent surveys, the World population is expected to increase by a billion in the next decade. Due to such unprecedented increase in population, energy demands are expected to soar high as well. And with most of the 'easy hydrocarbon' almost on the verge of depletion, it behooves us to remember that the total hydrocarbon reserve of the world is finite and it is dwindling every day. Thus it becomes

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incumbent to find new resources and develop efficient and economically feasible means of extracting the available ones [1].

One of the earliest works in this field could be traced back to Schlumberger *et al*., [2] who indicate the utility for measuring temperature of the wellbore fluid. Following this, there were a few developments in the area but it was not until two decades later that Moss and White [3] and Lesem *et al*., [4] came up with procedures to estimate wellbore fluid temperature. Edwardson *et al*., [5] were firstly to offer a theoretical sample to estimate temperature for fluid as a function of the production time and the well depth. Sagar *et al*., [6] made a significant improvement by extending Ramey's work to include multiphase flow and accounting for the kinetic energy effects and Joule - Thompson expansion using an empirical approach. Alves *et al*., [7] came up with the merged equation for temperatures of flowing which was applicable to both wellbores and pipelines, and degenerated into Ramey's equation for single phase incompressible liquid. In addition, they also accounted for convective heat transfer in the casing annulus, demonstrating excellent coherence with the field data. In more recent time, Hagoort [8] illustrated a graphic correlation to assessment the length of early passing period for the flowing well. This development was based on the result of revisiting Ramey's model on which Hagoort made further improvement by presenting an analytically solution for temperature of wellbore fluid of the gas wells. Hasan *et al*., [9] developed analytical models for transient wellbore fluid temperature for both draw-down and build-up for transient gas-well testing. Their models were validated with field data. Their model assumed conduction to be the only mode of significant heat transfer. Izgec *et al*., [10] proposed improvements to the previous analytic temperature models by developing a numerical differentiation scheme which removed the limitations imposed by the constant relaxation parameter assumption used in previous models. In a more recent study, Bahonar *et al*., [11] developed a numerically full implicit non-isothermal wellbore - reservoir simulator. They solve the heat transfer problem in much the same way as Hasan *et al*., [9] and stretch its application to the design of gas well tests and interpretation for the both non-isothermal gas reservoirs and isothermal. Mbaya and Amin [12] developed a new model for unsteady state flow of gas in the production wellbore with the general physical situation of the well such as the wellbore and surface materials, formation. Many researchers adopted researches on fluid flow and heat transfer in pipeline [13-21].

In this paper, modeling of velocity, pressure and temperature distribution, eddy viscosity, turbulent eddy dissipation, turbulent kinetic energy and heat transfer coefficient for the process of gas injection in wellbore.

2. Heat Transfer of the Wellbore

Two major classes of the models found in the literature for the quantitative temperature analyses.

The initial model was suggested by Ramey [22] in which analytical expressions for the wellbore temperature were obtained. This model considers the heat flow problem in steady-state by neglecting heat conduction in the vertical direction, changes in the fluid injection rate, horizontal temperature gradients, and any variations of either the heat capacities or the densities of the formation materials or the injected fluids. [23].

The second class includes McKinley's model (1986) and other similar models which rely on an energy balance for the produced fluids and neglect the formation properties provides a review of these models [23].

2.1 Formation of Temperature Distribution

The transient one-dimensional heat flow around the well is given by the following partial differential equation.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(k_i r\frac{\partial T_i}{\partial r}\right) = \rho_i c_{pi}\frac{\partial T_i}{\partial t} \tag{1}$$

Hasan and Kabir [24] developed a formation temperature distribution model, TD, applicable for a finite wellbore inner boundary condition that allows easy calculation of wellbore heat loss and flowing fluid temperature for steady state, two-phase flow. Initially the formation temperature remains unalterable with time and at the outer boundary the formation temperature does not change with radial distance.

The heat transfer between the surrounding formation and wellbore - soil interface as can be calculated according to the following ordinary differential equation.

$$\frac{dQ}{dz} = -\frac{2\pi K_e}{WK_D}(T_{wb} - T_e) \tag{2}$$

The temperature of the Wellbore fluid is controlled by the rate of heat loss from the wellbore to the surrounding formation, which in turn is a function of production/injection time and depth [24].

2.2 Energy Balance of the Wellbore Fluid

Ramey progressed an approximate solution to the conduction heat transfer problem involved in motion for fluid during the wellbore [25]. In this solution, two major assumptions are considered.

i. heat flow through different thermal resistances in the wellbore can be represented by steady state solutions.
ii. heat flows radially away from the wellbore (Figure 1) [23].

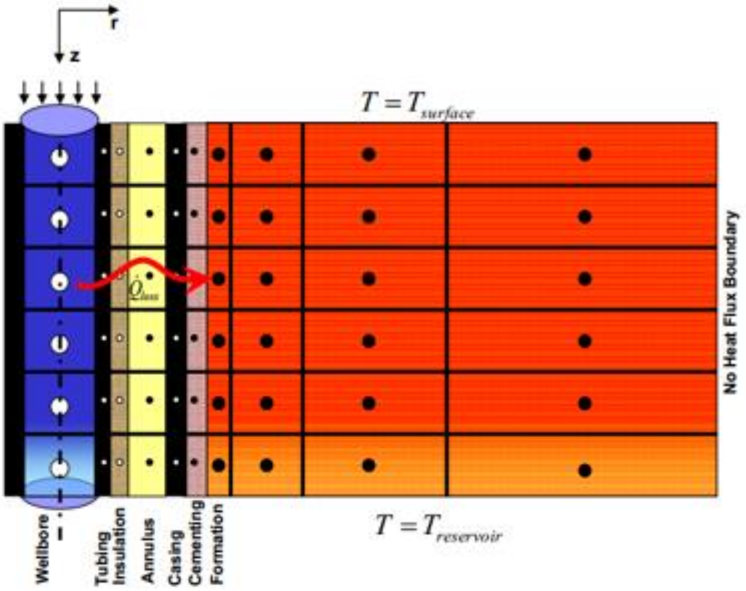

Fig. 1. Schematic diagram for the wellbore heat transfer [23]

By Ramey the classic model advanced beginning with total energy equation below.

$$dH + dE_{Potential} + dE_{Kinetic} = dQ \tag{3}$$

where
Q – the heat transfer
E – the energy
H – the enthalpy of fluid

2.3 Numerical Part

In this work, Modeling of fluid flow and heat transfer through stainless steel wellbore of outside tubing diameter of 0.073 m, inside casing diameter of 0.18 m, depth of 1.5 km, flow of crude oil (dynamic viscosity of $6.919\text{x}10^{-3}$ Pa.s, density of 871, thermal conductivity of 0.145 W/m.K) through a tubing with velocity of 7.12 m/s, temperature of 673 K. In the case of gas lift which includes injection of gas (air) in casing to enhance wellbore production, for our work, velocity of injected gas (air) was 0.01m/s, temperature of 573 K. All results were obtained using ANSYS Fluent Version 16.

3. Results and Discussion

3.1 Velocity Distribution

Figure 2 shows contour of velocity distribution of crude oil through tubing, the crude oil velocity seems to be decreased downstream throughout the tubing, this behavior can be clearly presented in Figure 3, which presents the velocity distribution of crude oil through the centerline tubing. The crude oil velocity was decreased along the tubing because of the losses cause the friction between tubing wall and crude oil.

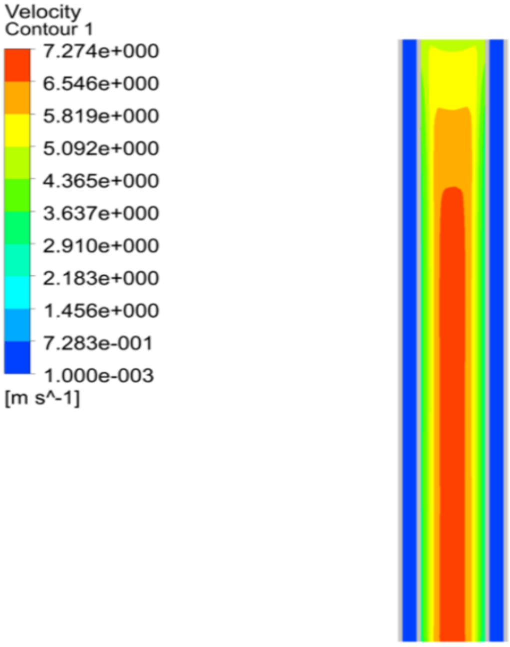

Fig. 2. Velocity contour of crude oil through the tubing

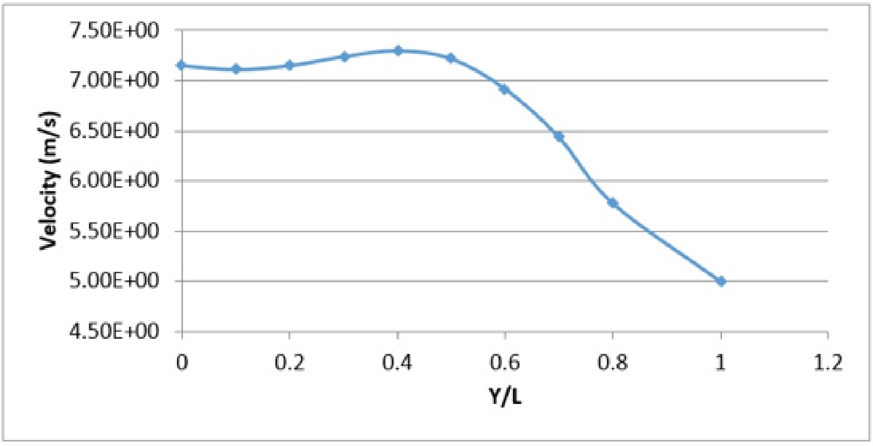

Fig. 3. Velocity distribution of crude oil through the tubing centerline

3.2 Pressure Distribution

Figure 4 presents contour of pressure distribution of crude oil through the tubing and it can be presented as pressure distribution in the tubing centerline, as shown in Figure 5. The pressure seems to be reduced throughout the tubing because of losses cause the friction between the tubing wall and crude oil.

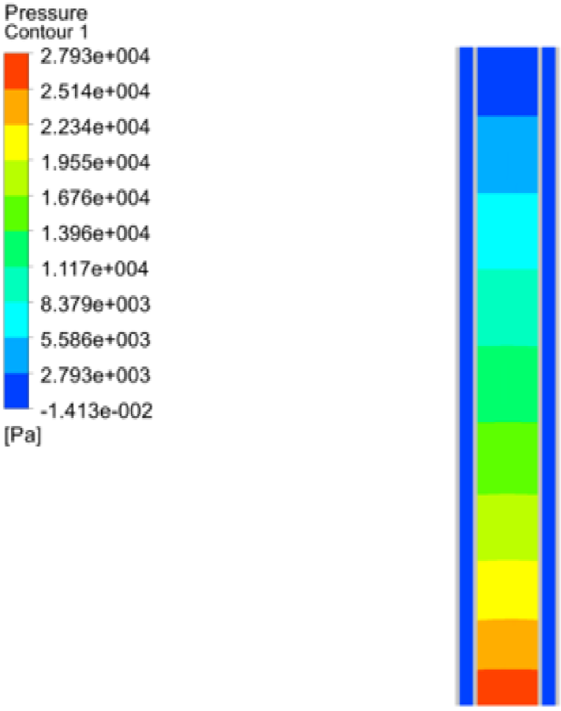

Fig. 4. Pressure contour of crude oil through the tubing

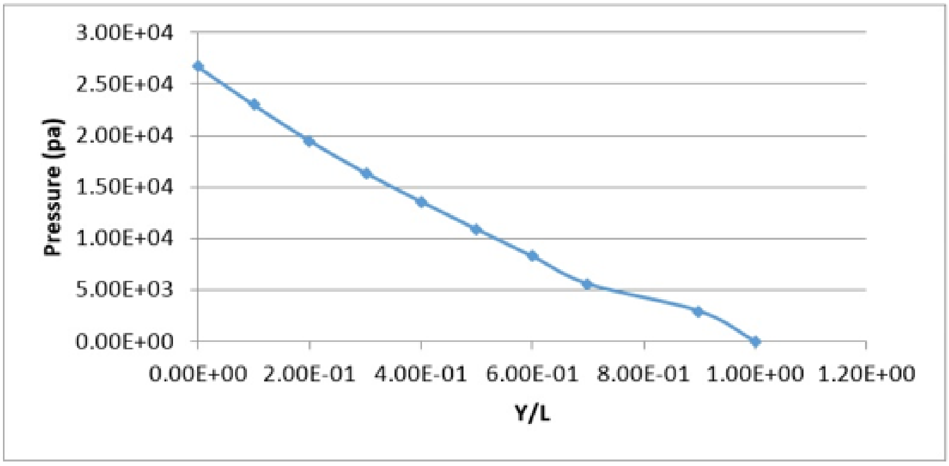

Fig. 5. Pressure distribution of crude oil through the tubing centerline

3.3 Eddy Viscosity

Viscosity causes shear stress in response to shearing of the flow. Eddies cause a similar effect, but they do it by physical moving faster fluid into slower regions and moving slower fluid into faster regions. Lots of little eddies make the fluid behave as though it had more viscosity. This phenomenon can be presented in Figure 6, which presents the contour of eddy viscosity of crude oil flowing through the tubing. Its value be larger at the entering and fluctuated between decrease and increase throughout the tubing as shown clearly in Figure 7.

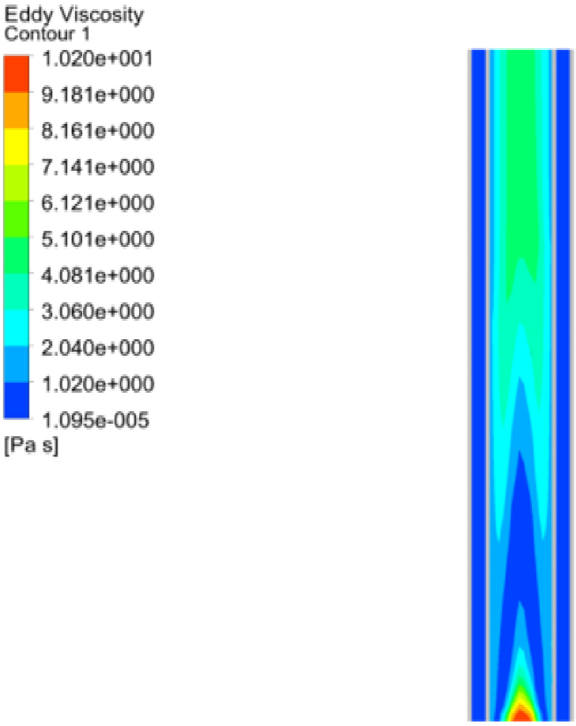

Fig. 6. Eddy viscosity contour of crude oil through the tubing

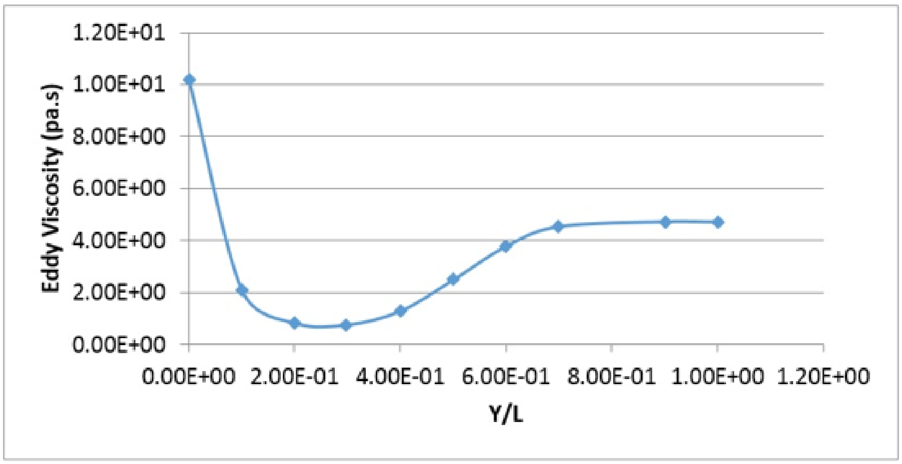

Fig. 7. Eddy viscosity distribution of crude oil through the tubing centerline

3.4 Turbulent Eddy Dissipation

The behavior of Turbulent Eddy Dissipation for the flow of crude oil upward through the tubing can be presented in Figure 8, which presents the contour of Turbulent Eddy Dissipation. Its value be large only at the entering (bottom) and gradually reduced along the tubing till it minimum value at the exit (top) as shown in Figure 9.

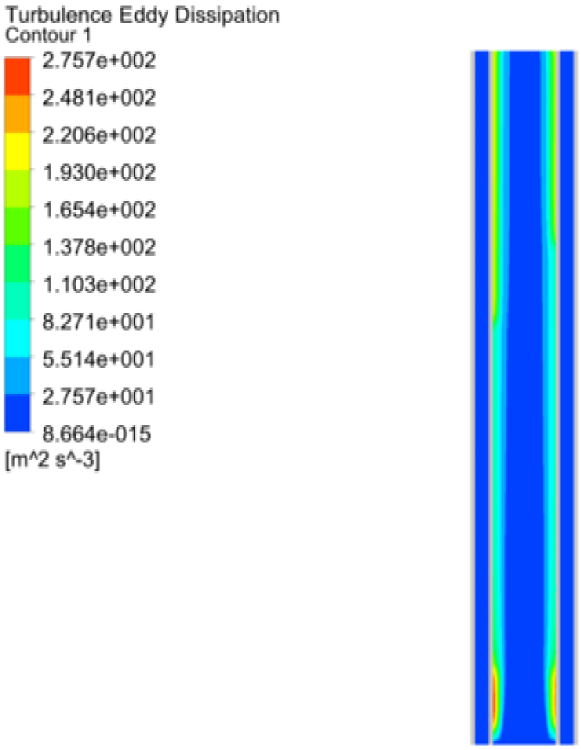

Fig. 8. Turbulent eddy dissipation contour of crude oil through the tubing

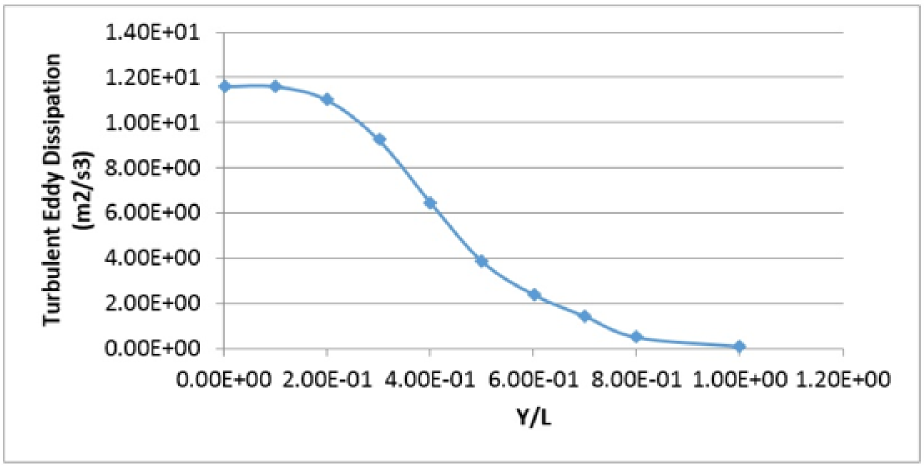

Fig. 9. Turbulent eddy dissipation distribution of crude oil through the tubing centerline

3.5 Turbulent Kinetic Energy

The turbulent kinetic energy can be defined as the variance of the fluctuations in velocity with dimensions of m^2/s^2. Figure 10 presents the turbulent kinetic energy for flowing of crude oil upward through the tubing, its values be larger be larger at the entering (bottom) and minimized throughout the tubing till it be in a lower value at the exit (top) as shown in Figure 11.

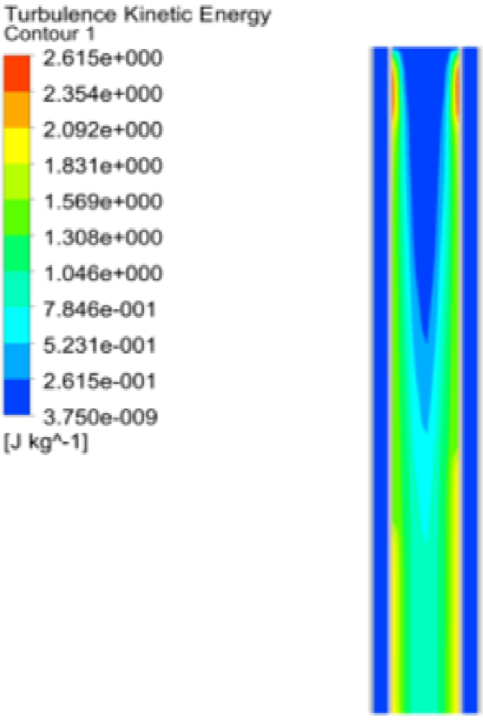

Fig. 10. Turbulent kinetic energy contour of crude oil through the tubing

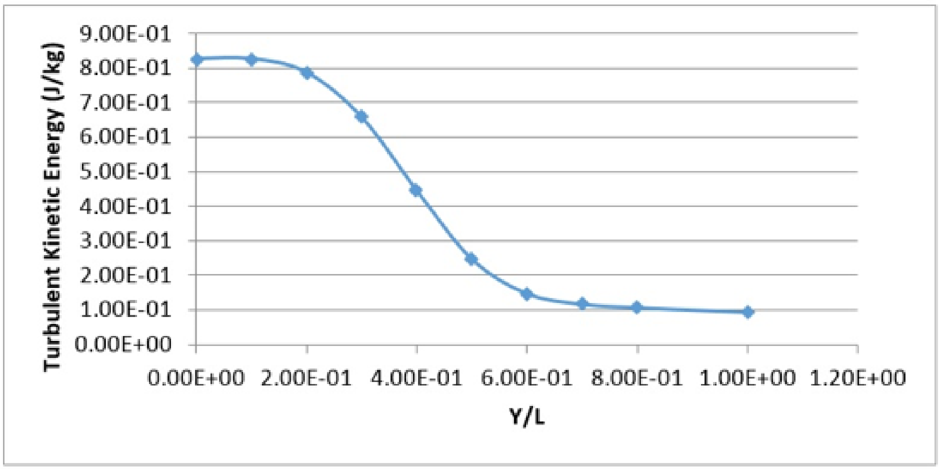

Fig. 11. Turbulent kinetic energy distribution of crude oil through the tubing centerline

3.6 Temperature Distribution

Figure 12 shows temperature distribution through the tubing centerline. It can be seen that crude oil temperature was decreased along the tubing centerline and the minimum value at the tubing exit (top) because of heat will be transfer from the crude oil (higher temperature) to gas (air) which have the lower temperature.

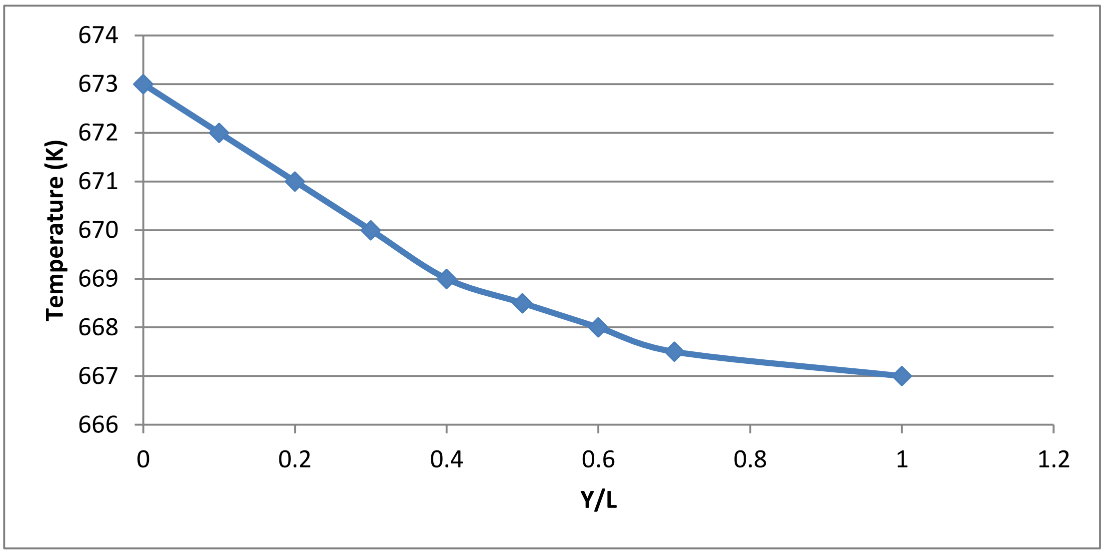

Fig. 12. Temperature of crude oil through the tubing centerline

3.7 Heat Transfer Coefficient

The coefficient of Heat transfer or Film effectiveness, or film coefficient is proportionality constant between thermodynamic temperature difference and heat flux and the, surface area where the heat transfer take place, its units of W/m^{2}K. This coefficient can be presented in Figure 13. Its value be minimum at the entering and increased suddenly through the (0.1) of the total tubing length, then stabilized till half of the total tubing length and suddenly increased through the last quarter of tubing.

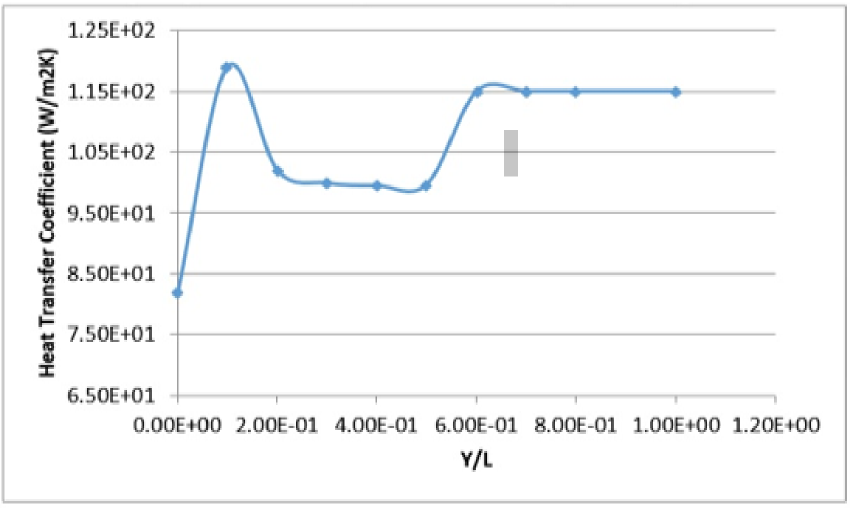

Fig. 13. Heat transfer coefficient of crude oil between the crude oil and tubing

4. Conclusions

The following conclusions can be drawn from the present project.

i. The crude oil velocity seems to be decreased downstream throughout the tubing.
ii. The pressure seems to be reduced throughout the tubing outcome of losses cause friction between the tubing wall and crude oil.
iii. Eddy viscosity of crude oil be larger at the entering and fluctuated between decrease and increase throughout the tubing.
iv. Turbulent eddy dissipation be large only at the entering (bottom) and gradually reduced along the tubing till it minimum value at the exit (top).
v. The turbulent kinetic energy be larger be larger at the entering (bottom) and minimized throughout the tubing till it be in a lower value at the exit (top).
vi. Crude oil temperature was decreased along the tubing centerline and the minimum value at the tubing exit (top).
vii. The heat transfer coefficient value be minimum at the entering and increased suddenly through the (0.1) of the total tubing length.

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