OPEN ACCESS

International
Journal
Of Modern Engineering Research (IJMER)

Application of Parabolic Trough Collectorfor Reduction of Pressure Drop in Oil Pipelines

Midhun V.C.[1], Dr. Shaji K.[2], Dr. Jithesh P.K.[3]

[1]*Department of Mechanical Engineering, Government Engineering College, Kozhikode, India.*
[2]*Department of Mechanical Engineering, Government Engineering College, Kozhikode, India.*
[3]*Department of Mechanical Engineering, Government Engineering College, Thrissur, India.*

ABSTRACT: *Pipelines are the least expensive and most effective method for the oil transportation. Due to high viscosity of crude oil, the pressure drop and pumping power requirements are very high. So it is necessary to bring down the viscosity of crude oil. Heated pipelines are used reduce the oil viscosity by increasing the oil temperature. Electrical heating and direct flame heating are the common method used for heating the oil pipeline. In this work, a new application of Parabolic Trough Collector in the field of oil pipeline transport is introduced for reducing pressure drop in oil pipelines. Oil pipeline is heated by applying concentrated solar radiation on the pipe surface using a Parabolic Trough Collector in which the oil pipeline acts as the absorber pipe. 3-D steady state analysis is carried out on a heated oil pipeline using commercial CFD software package ANSYS Fluent 14.5. In this work an effort is made to investigate the effect of concentrated solar radiation for reducing pressure drop in the oil pipeline. The results from the numerical analysis shows that the pressure drop in oil pipeline is get reduced by heating the pipe line using concentrated solar radiation. From this work, the application of PTC in oil pipeline transportation is justified.*

Keywords: *Oil pipeline, Pressure drop, Parabolic Trough Collector (PTC),Solarradiation, Viscosity*.

I. Introduction

The issues of environmental change brought on by contamination of air and water are expanding.This is principally because of the consistent misuse of fossil fuel assets. Serious international studies still foresee that in the next 20 years, at least 80% of the world's energy requirements will come from petroleum, natural gas and [1].The economic advancement is principally steered at the oil-gas area, which is intensified with transport issues. Currently,crude oil is the most important hydrocarbon resource in the world. Further increasing of these processes obviously can lead to the dangerous ecological situation. On the basis of aforementioned circumstances, fossil fuels saving and reducing the usage of hazardous substance, it is possible to economize by the gradual way of natural energy replacement into renewable energy.But the current energy scenario shows that it is impossible to be fully independent from conventional energy or fully dependent on renewable energy resources.So a hybrid energy schemes are required for a combination of non-conventional and renewable energy usage. The solar energy is one of the renewable energies which is the most essential, clean and inexhaustibly accessible renewable energy. The two main applications can be categorised into heating and producing electrical energy.This work is related to the utilization of solar energy to solve the transportation problem in the field of oil pipeline transportation.

Oil transportation is a complex and highly technical operation. There are different methods for the transportation of crude oil in which oil transportation using pipelines are the least expensive and most effective[1]. Due to the high viscosity of the crude oil, the pressure drop and pumping power requirement are very high.There are different technologies for transporting crude oil and bitumen via pipelines are discussed in [2].Simulation of classical pipe flow problem was conducted in [3]to study the effect of emissivity and absorptivity of oil pipe surface in outlet temperature of oil and found that friction factor and pressure losses are mainly affected by absorptivity and emissivity of exterior surface of pipe flow.The basic idea of heating the crude oil using solar energy can be seen in [4]which the author put forward the idea of initial crude oil treatment in oil field using solar energy so that the temperature of oil is elevated to decrease the oil viscosity.

Heating is one of the common methods used to reduce the crude oil viscosity for reducing pressure drop. In this proposed work, a steady state analysis is to be carried on oil pipeline with constant heat flux on its surface by applying concentrated solar radiation. The concentrated solar radiation is applied on the pipe surface using a Parabolic Trough Collector (PTC). The oil pipe acts as the absorber tube which absorbs the concentrated solar radiation from the PTC. Viscosity and density of oil is assumed to vary with temperature and other properties of the fluid is assumed to be constant. There will be a decrease in viscosity of the fluid with increase in fluid temperature due to the concentrated solar radiation falling on the pipe surface. This reduction in viscosity is expected to reduce pressure drop in the pipeline and reduces the required pumping effort. Even though there are some correlations for finding the pressure drop and heat transferred in the pipe but for using these it is necessary to find the bulk mean temperature from inlet and outlet fluid temperature. Thus experimental or numerical analysis is required for finding the outlet temperature of the fluid. This shows the significance of a three dimensional steady state analysis of pipe line using CFD technique to find the fluid outlet temperature and pressure drop inside the pipe. Inorder to find the effect of heating,the pressure drop in heated oil pipeline is compared with the pressure drop in adiabatic pipe. The hydrodynamic and thermal characteristics of the flow are investigated to explain the nature of flow inside the pipe.

II. Method

In this work, the main motive is to conduct a single phase three dimensional analysis of the flow through an oil pipeline to determine the pressure drop inside the pipeline with and without heating. So this analysis mainly focuses on the reduction of pressure drop by heating the oil pipe line. Numerical analysis of the oil pipe line is done by using CFD software tool ANSYS FLUENT 14.5. CFD simulation is carried out to compare the pressure drop and outlet temperature in oil pipelines.

The CFD analysis is carried out in Fluent 14.5. The equation for conservation of mass or continuity equation can be written as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1}$$

Above equation is the general form of the mass conservation equation is valid for incompressible as well as compressible flows.

Momentum Equation:

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_i}\left[(\mu + \mu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}(\mu + \mu_t)\frac{\partial u_l}{\partial x_l}\delta_j^i\right] + \rho g_i \tag{2}$$

Energy equation:

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left[\left(\frac{\mu}{Pr} + \frac{\mu_t}{\sigma_T}\right)\frac{\partial T}{\partial x_i}\right] + S_R \tag{3}$$

Transport equation for Realizable k-ε Model:

$$\frac{\partial}{\partial x_j}(\rho k u_j) = \frac{\partial}{\partial x_i}\left[(\mu + \mu_t)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \tag{4}$$

and

$$\frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right] + \rho C_1 S\varepsilon - \rho C_2\frac{\varepsilon^2}{k + \sqrt{\vartheta\varepsilon}} + C_3\frac{\varepsilon}{k}C_{3\varepsilon}G_b + S_\varepsilon \tag{5}$$

where $C_1 = \max\left[0.43, \frac{\eta}{\eta + 5}\right]$, $\eta = S\frac{k}{\varepsilon}$ and $S = \sqrt{2S_{ij}S_{ij}}$

G_k represents the generation of turbulence kinetic energy due to the mean velocity gradient, G_b is the generation of turbulence kinetic energy due to buoyancy, Y_M represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate. C_2 and $C_{1\varepsilon}$ are constants. σ_k and σ_ε are the turbulent Prandtl numbers for k and ε, respectively. S_R, S_k and S_ε are user-defined source terms.

Present analysis is based on the following assumptions:

1. Fluid flow is assumed to be in single phase.
2. The effect of gravity is not considered in the analysis.
3. The axial conduction at ends of the pipe domain is neglected.
4. Only the density and viscosity of the fluid is changing with temperature.
5. Heat flux around by direct and concentrated solar radiation on the absorber tube is taken in approximated manner.
6. Heat loss to the ground through radiation is neglected.
7. Inside surface of the pipe is assumed to be smooth.

2.1Geometry details

Figure 1 describes the fluid flow through oil pipeline of internal diameter of 0.02 m and external diameter of 0.025 m respectively. Adiabatic wall boundary conditionis provided over the entire surface of the oil pipe.Figures 2 describes about heating of the pipeline with wall boundary conditions necessary for heating the pipe. The computational domain of the problem is created by using ANSYS Design Modeler. Computational domain of the problem consists of fluid domain and solid domain. The pipe wall of 1 m from the inlet side is considered as adiabatic wall. The concentrated radiation is applied on base of the pipe surface by using a Parabolic Trough Collector (PTC) of rim angle 160^0. In heated region of the oil pipe, the concentrated solar radiation is applied on the bottom surface of the pipe and direct solar radiation is applied on the top surface.

2.2Mesh details

Meshing of the computational domain explained above was done by using ANSYS ICEM CFD in Ansys Workbench 14.5. The total elements in the domain are 435774 with 454608 nodes. The fluid and solid domain are created by sweep method. Inflation is provided in the fluid domain closer to the inside pipe wall so that fluid domain nearer to the pipe domain will be finely meshed which is necessary to incorporate the effect of thermal as well as hydrodynamic boundary layer. The surface of the computational domain is divided in to some parts for providing proper boundary conditions.

2.3 Material Properties

Iranian Light Dead crude oil is taken as working fluid and Aluminium as the pipe material. The heat capacity and thermal conductivity of crude oil are 1887 J/kg K and 0.1483 W/m K. The density is taken as a function of temperature:

$$\rho = -0.732T + 869.3 \quad (6)$$

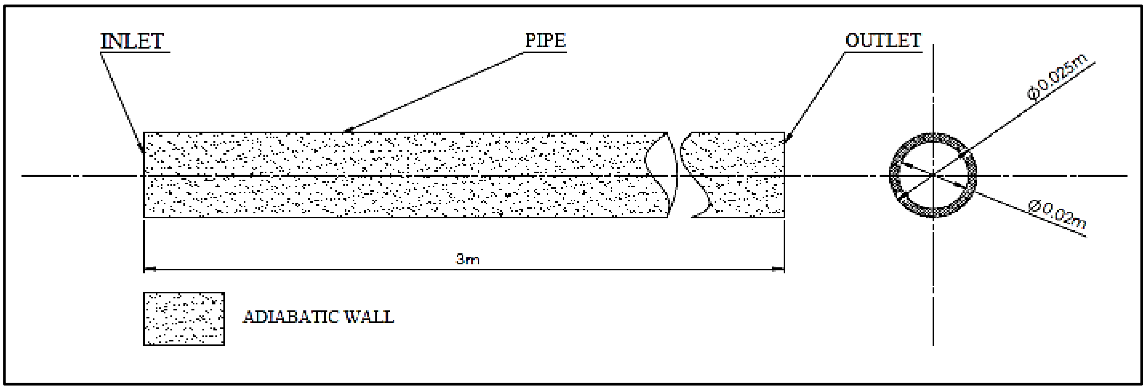

Figure 1: Adiabatic oil pipe

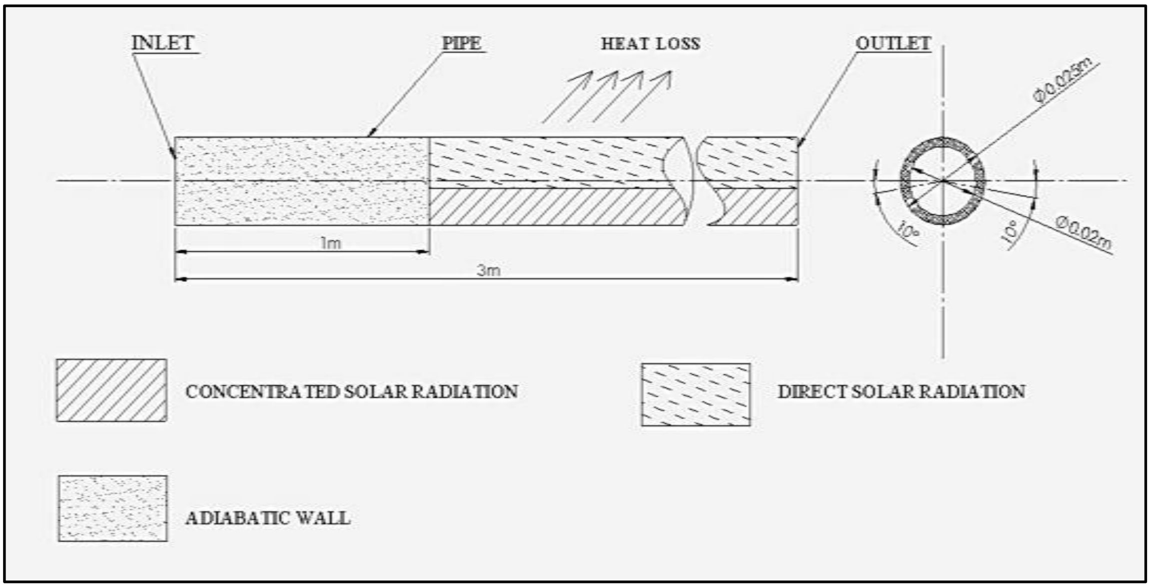

Figure2: Heated pipe with thermal leakage

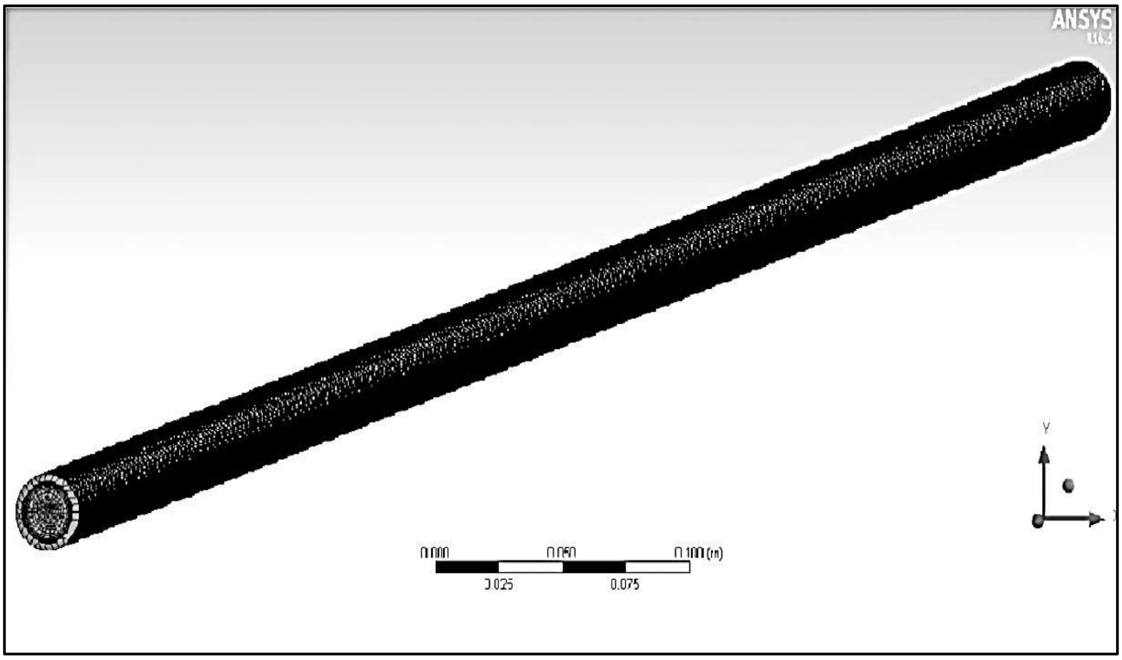

Figure 3 Computational domain after meshing

from[3] where T is in ^{0}C. The correlation for dynamic viscosity (μ) by [5] for Iranian light dead crude oil is used in the analysis:

$$\mu = a \times \frac{e^{\frac{b}{API}}}{API} \tag{7}$$

where $a = 0.00735T^2 - 4.3175T + 641.3572$, $b = -1.51T + 568.84$

In both case the dynamic viscosity μ is in centipoise (cP) and temperature T is in Kelvin (K). The conductivity of crude oil k = 0.1483 W/mK and heat capacityc_p =1887 J/kg K. Properties of Aluminium as ρ= 2719 kg/m^3, c_p=871 J/kg K,k = 871 W/mK respectively. The density, heat capacity and thermal conductivity of crude oil are 858.408 kg/m^3, and 0.1483 W/m K

Table I Parameters for the numerical study

D_{inner}	0.02 m
D_{outer}	0.025 m
L	3 m
T_i	298 K
u_i	2.12 m/s
μ_i	0.0094 Ns/m^2
ρ_i	851 Kg/m^3
k	0.1483 W/mK

2.4Solution Methodology

The governing equations were solved using the commercial software package of FLUENT from ANSYS 14.5. The second order upwind scheme was used for convective term discretization of momentum, energy, turbulent kinetic energy and turbulent dissipation whereas least square cell based scheme for gradients and standard for pressure equationquantities at cell faces are computed using a multidimensional linear reconstruction approach.. SIMPLE algorithm was used for pressure and velocity coupling. The solution was assumed to be converged when the difference was limited to the third decimal point for solution of velocity terms and the sixth decimal point for energy and continuity solutions.

2.5 Boundary Conditions

The inlet of the pipe is given with velocity inlet boundary condition with oil temperature of 298 K and outlet with pressure outlet condition. The inlet velocity is taken as 2.15 m/s and the corresponding Reynolds number at inlet is 4000. Inorder to prevent boiling of oil the Reynolds number is limited at 4000 and above. The operating pressure as 101.3 kPa and a gauge pressure of 0 Pa is given as the outlet pressure. For the analysis of insulated oil pipeline, the pipe wall is given with adiabatic wall condition whereas in the case of heated pipeline the pipe domain surface is split up in to two basic regions – adiabatic region and heated region. 1m length of pipe wall surface is given with adiabatic condition. The remaining part of the pipe surface is split in to four regions (top and bottom surface in each 1m length). The top surface of 2 m length of pipe is provided with wall boundary condition for applying the effect of direct solar radiation. The corresponding bottom portion of the pipe is also provided with wall boundary condition to account the effect of concentrated solar radiation. Heat generation (q_g''') equivalent to constant heat flux of 1000 W/m^2 is given to the top surface.Inaddition to that the effect of concentrated solar radiation is applied on the pipe surface in the form of heat generation on pipe surface equivalent to a constant heat flux (q'')of 120 kW/m^2. This equivalent value of heat generation is calculated by using the relation:

$$q_g''' \times \frac{\pi}{4}\left(\left(D_0+10^{-6}\right)^2 - D_0^{\,2}\right)\times L = q'' \times \pi\left(D_0\right)\times L \tag{8}$$

$D_0$is the outer diameter of the tube and L is the length of heated portion of the pipe. The heat generation (q_g''') is multiplied with volume formed by apparent thickness of 10^{-6} m on the surface of the pipe which is equated with the product of heat flux (q'') and the surface area of the pipe on which radiation falls.By using mixed type of wall boundary condition, the heating effect (by heat generation) along with convection and radiation losses from the pipe surface can be included.The heat transfer coefficient from the pipe to the surrounding can be calculated by a correlation against wind speed as from [6]:

$$h_0 = 5.7 + 3.8u_w \tag{9}$$

whereu_w is the wind velocity. In this work h_0 = 10 W/m^2 (for u_w = 1.13 m/s)

The convection loss with atmospheric is calculated based up on assuming the atmospheric temperature T_∞ = 300 K and convection coefficient h_0 = 10 W/m^2 K using (9) by taking wind velocity as 1.13 m/s. Radiation loss from the surface of the pipe to the sky is accounted by calculating the sky temperature by using the relation given in [7]:

$$T_{sky} = 0.0552T_\infty^{1.5} \tag{10}$$

from that T_{sky} = 286.82 K. The emissivity of sky ε_{sky} can be calculated by using Trinity equation:

$$\varepsilon_{sky} = 0.787 + 0.0028T_{dp} \tag{11}$$

where ε_{sky} = 0.83 for dew point temperature of 15.1^{0}C.

III. Results and Discussion

After the completion of the 3D steady state analysis of the oil pipeline, the pressure drop reduction due to heating by concentrated solar radiation on the pipe is mainly discussed in this section. For determining the associated factors which facilitate the reduction in pressure drop can be determined only through analysing thermal as well as hydrodynamic regimes of the flow inside the oil pipe. Also results obtained from the analysis are validated.

Figure 4shows the local pressure distribution along the pipe. From the figure it is clear that pressure drop in heated pipe is lower than the pressure drop in adiabatic pipe. The pressure drop in adiabatic pipe is 14196.8 Pa and in heated pipe the pressure drop is 12248 Pa. Therefore by using this method of heating we are able to achieve pressure drop reduction of 1947.4 Pa under above boundary conditions. Thus heating of the pipe using concentrated solar radiation has considerable effect in pressure drop reduction. This reduction in pressure drop is attained by reducing the viscosity of crude oil by heating. Since the viscosity is a strong function of temperature, the temperature rise of the fluid results in reduction of viscosity and thereby reducing the friction factor. This reduction in friction factor is mainly responsible for the reduction of pressure drop in the heated pipe.

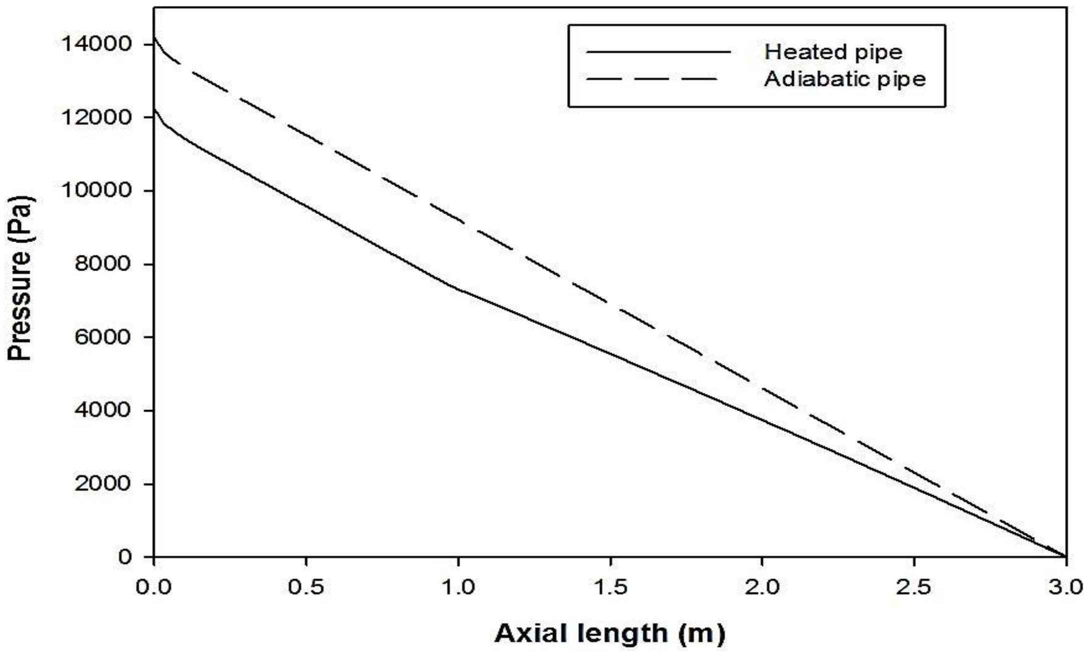

Figure 4:Pressure distribution along the axial length of pipe

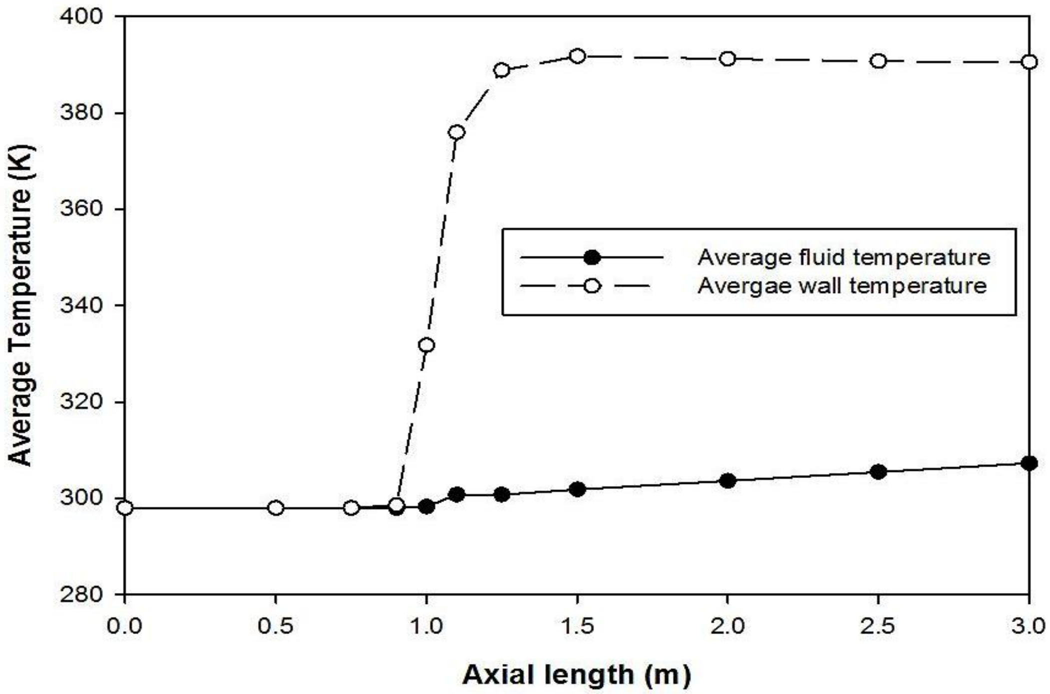

Figure 5:Variation of average fluid temperature and wall temperature with axial length

The average fluid temperature and wall temperature variation with axial length of the pipe are shown in Fig.5. Here the average wall temperature is taken by calculating the length average of temperature along a circle on the inner wall surface at different axial position of the pipe. This is because of the nonuniform heating around the pipe surface. At inlet side the average wall temperature is 298 K and this is maintained up to X = 0.75 m after that there is a sudden rise of temperature. About 1.25 m from the entrance, the average wall temperature almost attains a constant value of $T_{avg,\ w}$= 391 K.This is due to heat loss with surroundings. Due to the effect of direct and concentrated solar radiation, the fluid temperature will be non-uniform around the circumference of the pipe at each axial position. In order to get the average fluid temperature, area weighted average of the fluid temperature at different cross section of the fluid domain at different axial positions are taken. The heat from the pipe wall is absorbed by the oil by convection. Thus the oil temperature is increased along the axial length of the pipe. The average fluid temperature starts increasing from axial position X = 0.75 m even though the heating section of the pipe starts from X = 1 m by absorbing the thermal energy from the walls of heated pipe. Fluid temperature rise is linear in nature similar to the case of temperature variation of fluid in a pipe at constant heat flux condition. The rise of average fluid temperature is proportional to the length of heated pipe similar to the case of pipe heated with constant heat flux boundary condition.

The variation of friction factor (f) with dimensionless length in adiabatic and heated pipe is shown in the Fig. 6. Friction factor is higher at the entrance region due to higher velocity gradient and attains a constant value at fully developed region but here the pipe is heated by direct and concentrated solar radiation, so the viscosity and density of fluid are reduced. But viscosity variation is more rapid compared to the density so the Reynolds number of the flow is increased and the friction factorsteep decrease in the heated region when compared with adiabatic pipe. Friction factor is proportional to pressure drop inside a pipe so decrease in f results in reducing pressure drop. Thus reduction in f is the main factor for reducing the pressure drop. Another important observation can be made from the analysis is that at first the friction factor decreases with increase in axial length in the heated region of the pipe after that the friction factor has anincreasing trend towards the end of the pipe at higher heat flux case. This is due to the increase in velocity gradient near to the wall region. The fluid near to the wall will have more temperature, thus the fluid density decreases whereas the velocity of the fluid will increase. This increase in velocity results in increase of velocity gradient near the wall region and thus the friction factor increases which is observable from the Fig.6. This trend of increase in friction factor is not favourable for achieving pressure drop reduction. It indicates that length of heating and applied heat flux should be in a proper combination to attain maximum pressure drop reduction.

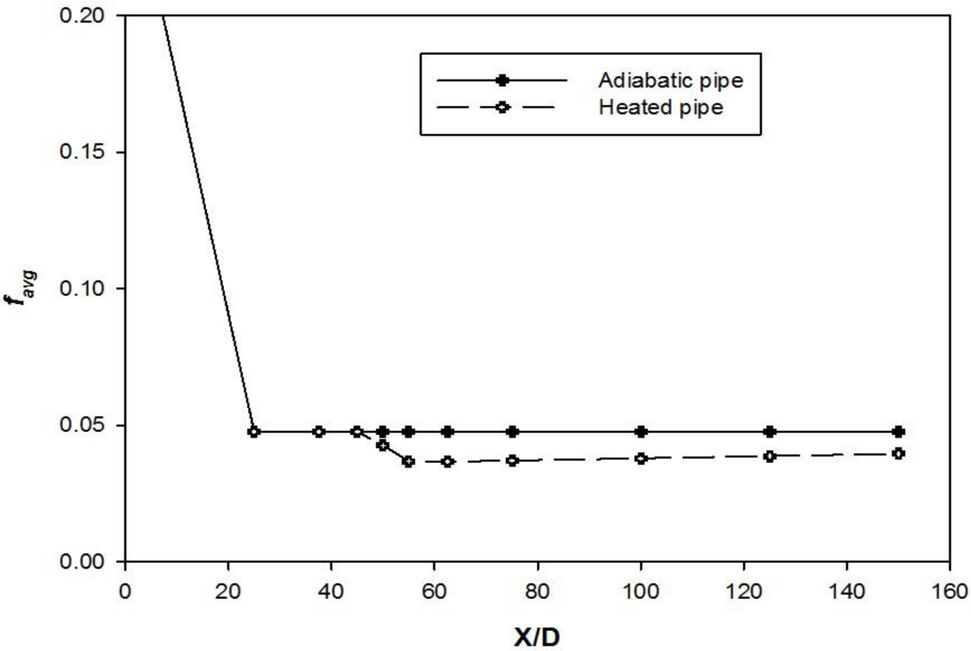

Figure6:Comparison of average friction factor in heated and adiabatic pipe

For validating this work, the friction factor obtained from the CFD analysis is compared withFirst Petkhov's equation:

$$f = (0.79 \ln Re - 164)^{-2} \tag{12}$$

from [7] where the fluid properties have to be evaluated at bulk mean temperature

$$T_{bulk\,mean} = \frac{T_{avg,f,i} + T_{avg,f,o}}{2} = \frac{298 + 307.283}{2} = 302.642\,K$$

UsingPetkhov's equation we get f = 0.0386 and it is compared with the values obtained from the CFD analysis as shown in Fig.7.Friction factor obtained from analysis agrees with Petkhov's equation with an error of 6.8%.

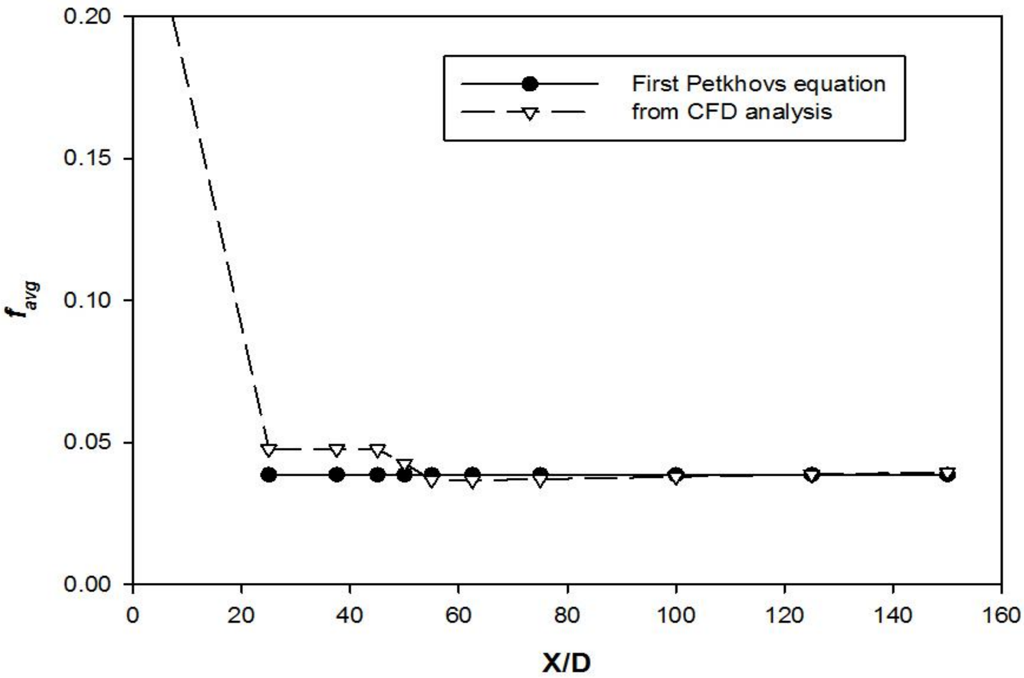

Figure 7:Validation of average friction factor f_{avg}

IV. Conclusions

The 3-D steady state analysis of the oil pipeline is carried out with the effect of concentrated solar radiation falling on the pipe surface by using PTC. The pressure drop reduction achieved by this method of heating is analysed and major conclusions from the analysis are summarised as follows:

1. The three dimensional steady state analysis of the oil pipe line is completed and results are validated.
2. The method of heating the oil pipeline using Parabolic Trough Collector (PTC) to reduce the pressure drop inside the pipe is effective.
3. Friction factor is reduced by heating the crude oil. Due to the increase in fluid temperature the dynamic viscosity of the fluid decreases and this is mainly responsible forreducing pressure drop reduction.
4. New application of PTC in oil pipeline transportation is justified.
5. A very small increase in friction factor can be observed in the pipe outlet due to localised increase in fluid velocity near pipe wall.

The effect of heat loss in pressure drop reduction can be studied by comparing the results of above case with a heated pipe without heat loss. In this work, the distribution of concentrated solar radiation from the PTC falling on the bottom surface of the pipe is taken in an approximated manner. It is possible to provide the actual heat flux distribution around the pipe by using ray tracing techniques.

Nomenclature

D	Diameter (m)
f	friction factor
h	Convective heat transfer coefficient
k	Thermal conductivity of fluid (W/mK)
P	Pressure (Pa)
q'''	Volumetric heat generation rate (W/m^3)
q''	Rate of heat transfer per unit area (W/m^2)
Re	Reynolds number
T	Temperature (K)
u	Velocity (m/s)

Greek Symbols

μ	Dynamic viscosity
ν	kinematic viscosity
ρ	density
ε	emissivity
σ	Stefan Boltzsmann constant (5.67×10^{-8} W/m^{2}K^4)

Subscript

∞	Atmosphere
avg	Average
dp	Dew Point
f	Fluid
o	Outer
w	Wall

REFERENCES

[1]. **R.M. Palou, M. L.Mosqueira, B. Z. Rendón, E. Mar-Juárez, C. B. Huicochea, J. C.Clavel-López, Jorge Aburto**, Transportation of heavy and extra-heavy crude oil by pipeline: A review, *Journal of Petroleum Science and Engineering75* (2011), 274–282

[2]. **Abarasi Hart,** A review of technologies for transporting heavy crude oil and bitumen via pipelines, *Journal of Petroleum Exploration and Production Technology*, 2013

[3]. **AndishehTavakoli, MohamadrezaBaktash**, Numerical Approach for Temperature Development of Horizontal Pipe Flow with Thermal Leakage to Ambient ,*International Journal of Modern Engineering Research, Vol.2, Issue.5*, Sep-Oct. 2012, 3784-3794

[4]. **F. Mammadov**, Application of solar energy in the initial crude oil treatment process in oil fields,*Journal of Energy in Southern Africa,Vol 17 No 2,* 2009.

[5]. **M. Sattarina, H. Modarresi, M. Bayata, M. Teymoria**, New Viscosity Correlations For Dead Crude Oils, *Petroleum & Coal* ISSN 1335-3055, 2007.

[6]. **J. A. Duffie, W. A. Beckman**,*Solar engineering of thermal Processes*, (Wiley Publication,1991).

[7]. **V.B. Sharma, S.C. Mullick**, (1991), Estimation of heat-transfer coefficients, the upward heat flow, and evaporation in a solar still, *Journal of Solar Engineering.*, 113, pp. 36–41.

[8]. **Y.A. Cengel,***Heat Transfer A Practical Approach*, (Tata McGraw-Hill Publication) p-441.

[9]. **R. Forristall**, (2003), Heat Transfer Analysis and Modeling of a Parabolic Trough Solar Receiver Implemented in Engineering Equation Solver, *Technical report National Renewable Energy Laboratory*, U.S. Department of Energy Laboratory

[10]. **Hank, Price, L. Eckhard, David Kearney, Eduardo Zarza, Gilbert Cohen, Randy Gee, Rod Mahoney**, (2002), Advances in Parabolic Trough Solar Power Technology *Journal of Solar Energy Engineering, ASME.*

[11]. **A Saniere, I. Henaut, J.F. Argillier**,(2004), Pipeline transportation of heavy oils, a strategic, economic and technological challenge. Oil Gas SciTechnol Rev IFP 59(5):455–466

[12]. **M.Roesle, V.Coskun, A.Steinfeld**, (2013), Numerical Analysis of Heat Loss From a Parabolic Trough Absorber Tube With Active Vacuum System, *Journal of Solar Energy Engineering*, 2011, Vol. 133 / 031015-1.