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Research note

Uncertainty Reduction of Metering System in Kharg Island Oil Terminal by Adjusting Pipe Line Volume Flow rate

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Abstract
Accurate crude oil measurement at the metering station is one of main aims in an oil export terminal. The main objective is to decrease or remove any error at the metering station. It is found that crude oil temperature at metering station has significant effects on measured volume and may cause big uncertainty at the metering point, as crude oil flows through the pipeline pick up the solar radiation and heat up. This causes the crude oil temperature at the metering point to rise and higher uncertainty to be created. The amount of temperature rise depends on the main pipeline flow rate. In Kharg Island, there is about a 3 km distance between crude oil storage tanks and the metering point. The crude oil flows through the pipeline due to gravity effects as storage tanks are located 60m higher than the metering point. The flow rate could be controlled by the appropriate valves. In this study, based on the climate and geographical conditions of Kharg Island, the temperature at the metering point has been calculated and the effects of main pipe line flow rate have been investigated. Further, the uncertainty in the measurement system due to temperature rise has been studied.

Keywords: *Oil Pipeline, Outlet Oil Temperature, Volume Measurement, Uncertainty in Metering System, Solar Radiation*

1- Introduction

Accurate measurement of crude oil in an oil export terminal is a primary objective. Any type of measurement error can result in a financial loss, whether it is to the buyer or the seller. Such errors are due to inaccuracies that occur during the custody transfer process and result in the buyer receiving more or less product than contracted. Three primary sources of error in crude oil measurement include a) Volume measurement b) Sediment and water c) temperature rise. Accurate temperature compensation of gross measured volume is critical to overall volume measurement accuracy.

Here, by considering the Kharg Island climate conditions, solar radiation has a predominant effect on crude oil temperature rise inside the pipeline. As Kharg Island is the main Iranian oil export terminal, the accuracy of measurement is a very important issue. Considering the fact that, the flow rate has an effect on crude oil temperature rise; its effects on the accuracy of the measurement

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system have been investigated. At the fields of effect of solar radiation on temperature variation in pipe flow there have been previous studies such as, Kowsary and Pourshaghaghy [1], who have considered a more realistic situation in which dissipation of the heat through the outer surface to the ambient has been considered. They computed temperature development in pipe flow by considering thermal leakage by a heater element that showed bulk temperature tends to a limiting value along the pipe. Yaghoubi et al. [2] estimated the temperature of oil inside the cylindrical receiver for the Shiraz solar power plant; it was supposed an unsteady state condition and neglected conduction variation along the pipe, obtaining a nonlinear partial differential equation system and was solved by numerical method. Madani [3] calculated temperature distribution of water inside the cylindrical tube with a black cover by a simple model of overall coefficient of heat losses. In this work, we suppose an hourly steady state situation in pipe flow where the temperature of the oil and pipe vary in the direction of flow. Kim et al. [4] obtained the thermal performance of a solar system composed of parallel, all-glass (double skin) vacuum tubes by using a one-dimensional analytical model; they supposed a constant heat flux around the tube under unsteady state condition; Han et al. [5] continued the same work with three-dimensional model and compared the results with a one-dimensional model and showed that they are in good agreement with each other.

In the present research, the effect of solar irradiation on incompressible flow inside an aboveground pipeline is investigated theoretically and numerically. A mathematical model is developed to calculate the theoretical oil temperature with different flow rate within a specific pipeline. The outer surface of the pipeline is exposed to solar radiation and wind stream. The radiation heat exchange with ambient is also taken into account. For simplifying the model, hourly steady state situation in pipe flow has been assumed. In most studies such as Suehrcke et al. [6] and Sahin and Kalyon [7], because of using thermal resistance of radiation to sky, pipe surface temperature is assumed constant; while in this paper pipe surface temperature variation along the flow is taken into account. The model has been applied to a specific crude oil pipeline. The pipeline is located in Kharg Island, the main Iranian export terminal, and delivers the crude oil from storage tanks to the exporting ship. The effects of pipeline volume flow rate are investigated theoretically and numerically under the relative weather conditions of Kharg Island.

Initially, the amount of absorbed solar energy by surface has been estimated for the Kharg Island climate condition. Then by computing the convection heat transfer coefficient the outlet oil temperature was calculated by employing energy balance along the pipe line for a day (5th June 2008). Finally, by catching the relationship between temperature and error, the uncertainty in crude oil volume measurement has been calculated. It is found that volume flow rate is an important parameter on the variation of oil temperature and caused considerable uncertainty in oil measurement.

2- Problem description

The problem under investigation is heat transfer from the horizontal pipe with viscous fluid flow inside. Figure 1 shows the geometry and the configuration of the problem which is based on the actual condition of the Kharg Island oil terminal. Crude oil flows from a storage tank at a 60 m height along the pipeline having a length about 3 Km as shown in the following Fig. 1; after the end of the pipeline, oil arrived at the metering station for export. It is obvious that oil temperature was affected along this long pipeline by solar radiation. We want to obtain the daily outlet oil temperature from the pipeline; then with the relationship between the temperature and metering uncertainty, we estimate the uncertainty of oil metering.

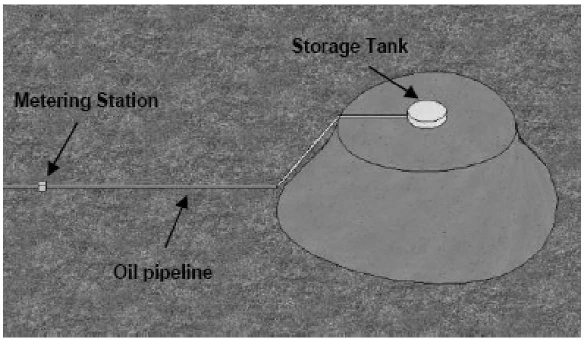


Figure 1. Schematic diagram of oil pipeline system with storage tank in Kharg Island

Solar radiation over pipe increases the heat load during the day, but wind on the other side has an effective role to decrease the rate of heat transfer and the reduction of heat load to the pipe. The inlet temperature of the fluid is T_{fi} and the outlet temperature is T_{fo}. Because the length of the pipe is much longer than its diameter, the problem is assumed to be one-dimensional with temperature variations along the pipe (x direction). The parameters which are kept constant during the investigation are the pipe's diameter D and length of pipe L. The Kharg oil pipeline surface color is off-white, and was shown as Fig. 2. It is assumed that the problem is one-dimensional with temperature variation along the pipe flow (x direction).

Figure 2. The Kharg oil pipeline under investigation.

Table 1 shows relative parameters for the case study.

Table 1. Parameters used in the case study.

Parameter	Value
L(m)	3000
Do(m)	1.0668
Di(m)	1.04774
K_{pipe}(W/m.K)	30
T_{fi}(C)	30
T_{si}(C)	30

The working fluid is chosen to be light crude oil. Oil carries the maximum heat from the pipe due to its thermal and physical properties. Table 2 gives the thermal and physical properties of the selected fluids. The flow is assumed to be fully developed.

Table 2. Thermal properties of crude oil at 15.5°C.

Fluid	**ρ** (kg/m3)	**Cp** (KJ/kg°C)	**K** (W/m.K)	**μ** (Pa.s)
Light 0il	858.4081	1.887	0.1483	0.00145

3- Mathematical modeling

3.1- Solar radiation

Solar radiation is the primary phenomena which affects temperature variation of surfaces. To be able to estimate pipe and fluid temperature, solar radiation should be calculated in the first step. Theoretically, Wang et al. [8] showed solar radiation striking the earth's atmosphere usually brings 1.5 kW per square meter per hour (measured normal to the sun's rays), part of this is reflected, part is scattered, and part is absorbed by the atmosphere.

For estimating solar radiation many engineering models have been developed and proposed (Zekai [9]). In all of these models, the weather condition and location are important factors. Iranian researchers have examined various models including Angstrom, Bristow & Campbell, and Hargreaves and Reddy for Iranian cities, and compared them with measured values (Kamali and Moradi [10]). These models have also been modified by taking into account some other relevant meteorological variables and some suggested coefficients for the difference regions. Kamali and Moradi [10] suggested that the Angstrom model is more suitable for Khark Island. Therefore, the Angstrom model has been employed in this study to calculate solar radiation.

Based on the Angstrom model, solar radiation can be estimated using the following equation as,

$$\frac{I}{I_o} = a + b\frac{s}{s_o} \tag{1}$$

Where for Khark Island, a=0.37 and b=0.35 in spring & summer, and a=0.37 and b=0.38 in autumn & winter (Kamali and Moradi [10]).

The solar declination (δ), the main sunshine hour angle (ω_s) and the maximum possible sunshine duration day length (S_o) were calculated by Cooper [11] as,

$$\delta = 23.45\ \sin\ [\frac{360}{365}(284 + n)] \tag{2}$$

$$\omega_s = Arc\cos(-\tan\phi.\tan\delta) \tag{3}$$

$$s_o = \frac{2}{15}\omega_s \tag{4}$$

The cloudless hourly global irradiation received can be calculated using the following equation:

$$I_o = \frac{24\times 3600}{\pi} I_{sc}(1 + 0.033\cos(\frac{360n}{365}) [\cos\phi\cos\delta(\sin\omega_2 - \sin\omega_1) + \frac{2\pi(\omega_2 - \omega_1)}{360}\sin\phi\sin\delta] \tag{5}$$

In this equation, I_{sc} has adopted a value of 1367 W/m^2 according to the world radiation center and ω is solar hour as given by the following equation recommended by Duffie and Beckman [12] as,

$$\omega = 15(t - 12) \tag{6}$$

The pipeline in the presented study is located at Khark island situated (Latitude: 29° and Longitude 51°). Solar energy can be varied by geographical situation. The model was solved for the climatic conditions of Khark, representing southern Iran for the typical days (5th June 2008) of summer.

We estimated solar radiation in the horizontal surface already; for calculation of solar radiation on the pipe surface, the following steps are taken into account. The total radiation on the pipe surface consists of three components: beam solar radiation, sky diffuse radiation, and ground-reflected radiation. The total radiation calculated by:

$$I_T = I_b R_b + \frac{I_d}{2} + \rho_g \frac{I}{2} \tag{7}$$

While Reflectance of ground is considered as ρ_g = 0.2; the equations are presented in ASHRAE [13], Handbook of Fundamentals. In the above equation, R_b is calculated as

$$R_b = \frac{\left[1-(\cos\phi\sin\delta-\sin\phi\cos\delta\cos\omega)^2\right]^{1/2}}{\cos\phi\cos\delta\cos\omega+\sin\phi\sin\delta} \tag{8}$$

The total hourly horizontal solar radiation, I, can be obtained from Eq. (1). However, data on beam solar radiation I_b and diffuse solar radiation I_d are not available. Therefore, a correlation between horizontal diffuse, I_d, and total horizontal solar radiation, I, is required. A correlation between horizontal diffuse and horizontal total solar radiation as recommended by Yik et al. [14]:

For $0 \le K_T < 0.325$ (9)

For $0.325 \le K_T \le 0.679$ (10)

For $K_T > 0.679$ (11)

The sky clearness, K_T, is defined as ratio of the total horizontal radiation, I, to extraterrestrial radiation, I_o. By using the above equations, horizontal diffuse solar radiation, I_d, can be evaluated. Thus the horizontal beam solar radiation, I_b, can be obtained as recommended by McQuiston and Spitler [15] as follows:

$$I_b = I - I_d \tag{12}$$

Figure 3 shows amount of solar radiation on horizontal surface and air temperature for 5th June 2008. The radiation usually exists between 6 am to 18pm.

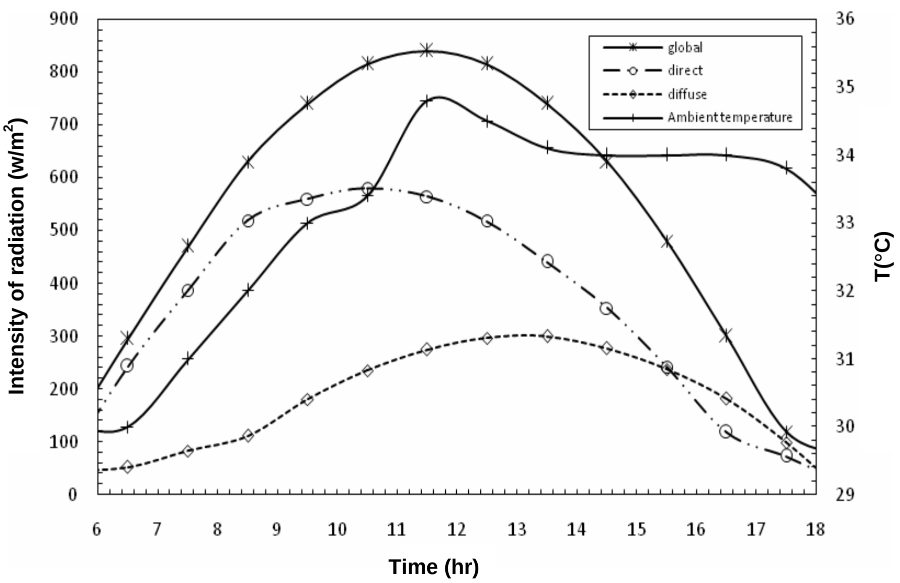


Figure 3. Solar intensity on horizontal surface at Kharg Island in June

3.2- Convective heat transfer

In order to estimate the convective heat transfer in outside pipe flow, we can use the concept of mixed convection. The directions of air motion due to natural and forced convection are approximately perpendicular. The flow and heat transfer around a circular cylinder in cross flow has been investigated extensively in the past. For example, Nayak and Sandborn [16] studied, experimentally, heat transfer from small circular cylinders placed horizontal to a downward flowing air stream.

For forced convection, and combined free and forced convection from horizontal tube, several correlations for various flow regions and flow Reynolds number are proposed. Such correlations can be found in Holman [17]. The most widely used correlation to estimate convection coefficient over a horizontal pipe in cross flow is (Holman [17]),

$$0.7<Pr<500 \;\&\; 1<Re_D<106 \qquad (13)$$

Where all properties are evaluated at T_∞, except Pr_s, which is evaluated at T_s, the cylinder surface temperature. Values of C and m are given in Holman [17]. If $Pr \leq 10$, $n = 0.37$; if $Pr > 10$, $n = 0.36$.

Convection coefficient can be obtained from Eq. (13) and by considering wind velocity in June. Results of convection coefficient are brought here as follow Fig. (4).

Using the measured values of solar intensity, wind velocity, ambient temperature and convection coefficient at the Kharg Island area as input data, the outlet oil temperature is calculated. One dimensional flow is considered taking into account that the dimensions in x direction are much longer than the y, Z. The color surface reflects and absorbs normal solar radiation flux. Absorbed solar radiation flux increases the surface temperature and is transferred by conduction to the inside of the pipe, then the temperature of fluid is increased. In order to obtain the temperature profile of fluid inside, a differential energy balance was carried out. The following assumptions for energy balance equations are considered:

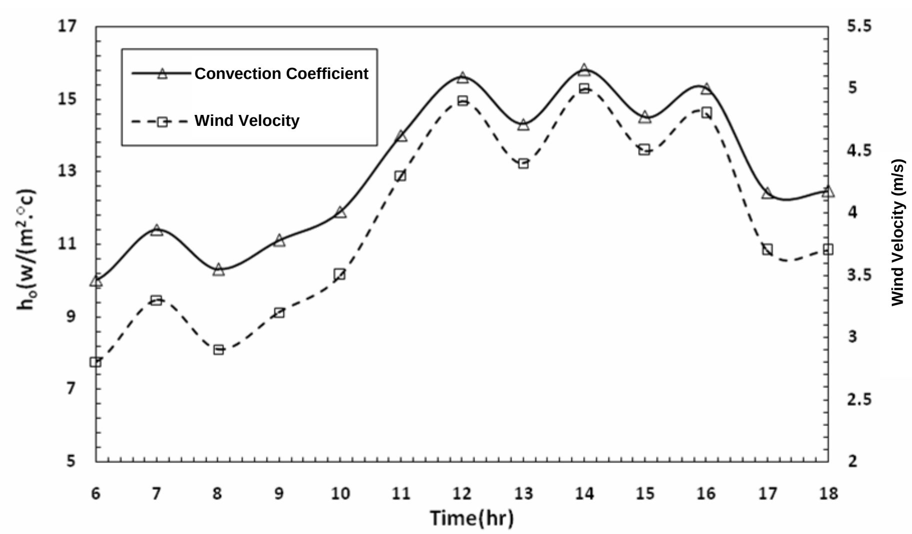


Figure 4. Convection coefficient during day in June

1. Temperature gradient across the thickness of the pipe is insignificant.
2. Heat transfer coefficient is considered to be constant at the selected time interval.
3. The surface color is opaque with constant absorptivity and emissivity.
4. The variations in the absorptivity and transmissivity of the color surfaces with the variation in angle of the incoming radiation are neglected.
5. Fluid properties are independent of temperature and mean amount is considered.
6. Heat conduction variation along fluid flow is neglected.

The energy balance equations for pipe, control volume 1, and fluid, control volume 2, which could be written and presented as:

For volume control (1):

$$Q_{conduction\_x} + Q_{solar} = Q_{sky} + Q_{conduction\_x+dx} + Q_{convection\_ambient} + Q_{convection\_fluid} \quad (14)$$

With substitution,

$$-kA'\frac{dT_s}{dx} + \frac{\alpha I_T(\pi D_o)}{2} = \varepsilon\sigma(\pi D_o)(T_s^4 - T_{sky}^4) + (-kA'\frac{dT_s}{dx} - kA'\frac{d^2T_s}{dx^2}) + h_o(\pi D_o)(T_s - T_\infty) + h_i i(\pi D_i)(T_s - T_f) \quad (15)$$

That $A' = \frac{\pi(D_o^2 - D_i^2)}{4}$, where the sky temperature is given by Sharma and Mullick [18] as,

$$T_{sky} = 0.0552 T_\infty^{1.5} \quad (16)$$

After simplification we have,

$$\frac{k}{4}(D_0 - \frac{D_i^2}{D_0})\frac{d^2T_s}{dx^2} - (h_0 + h_i\frac{D_i}{D_0})T_s + h_i\frac{D_i}{D_0}T_f - \varepsilon\sigma T_s^4 = -\frac{\alpha I_T}{2} - h_0 T_\infty - \varepsilon\sigma T_\infty^4 \quad (17)$$

The pipe surface temperature differences within the flow are assumed to be sufficiently small so that T_s^4 may be expressed as a linear function of temperature. This is done by expanding T_s^4 in a Taylor series about the free-stream temperature T_∞ and neglecting higher-order terms to yield,

$$T_s^4 \cong 4T_\infty^3 T_s - 3T_\infty^4 \quad (18)$$

Substitution Eq. (18) into Eq. (17) we have,

$$\frac{k}{4}(D_0 - \frac{D_i^2}{D_0})\frac{d^2T_s}{dx^2} - (h_0 + h_i\frac{D_i}{D_0})T_s + h_i\frac{D_i}{D_0}T_f - \varepsilon\sigma(4T_\infty^3 T_s - 3T_\infty^4) = -\frac{\alpha I_T}{2} - h_0 T_\infty - \varepsilon\sigma T_\infty^4 \quad (19)$$

After simplification, Eq. (19) can be written as:

$$\frac{k}{4}(D_0 - \frac{D_i^2}{D_0})\frac{d^2T_s}{dx^2} - (h_0 + h_i\frac{D_i}{D_0} + 4\varepsilon\sigma T_\infty^3)T_s + h_i\frac{D_i}{D_0}T_f = -\frac{\alpha I_T}{2} - h_0 T_\infty - \varepsilon\sigma T_\infty^4 - 3T_\infty^4 \quad (20)$$

For volume control (2):

$$\rho QCp\frac{dT_f}{dx} = h_i \pi D_i(T_s - T_f) \quad (21)$$

Where T_s can be written as,

$$T_s = \frac{\rho QCp}{h_i \pi D_i}\frac{dT_f}{dx} + T_f \quad (22)$$

By substituting Eq. (22) into Eq. (20), Eq. (20) can be written as,

$$a_1 \frac{d^3T_f}{dx^3} + a_2 \frac{d^2T_f}{dx^2} + a_3 \frac{dT_f}{dx} + a_4 T_f = d \quad (23)$$

In which

$$a_1 = \frac{\rho QCp(D_o - \frac{D_i^2}{D_o})k}{4\pi D_i h_i}, \quad a_2 = \frac{k(D_o - \frac{D_i^2}{D_o})}{4},$$

$$a_3 = \frac{-\rho QCp}{\pi D_i h_i}(h_o + h_i \frac{D_i}{D_o} + 4\varepsilon\sigma T_\infty^3),$$

$$a_4 = -(h_o + h_i \frac{D_i}{D_o} + 4\varepsilon\sigma T_\infty^3) + h_i \frac{D_i}{D_o} \text{ and}$$

$$d = -\frac{\alpha I_T}{2} - h_o T_\infty - \varepsilon\sigma T_{sky}^4 - 3\varepsilon\sigma T_\infty^4$$

Eq. (23) is nonhomogeneous ordinary differential equation from third order; boundary conditions for this differential equation are:

1. Inlet fluid temperature is defined: $T_f(0)$ = defined.
2. Inlet pipe surface temperature is defined then from Eq. (18): $(\frac{dT_f}{dx})_{x=0} = \frac{h_i \pi D_i}{\rho QCp}[T_s(0) - T_f(0)]$.
3. Fluid temperature at infinite condition is finite: $T_f(\infty)$ = finite.

The total solution of Eq. (23) is given as,

$$T_f(x) = c_1 e^{\lambda_1 x} + c_2 e^{\lambda_2 x} + c_3 e^{\lambda_3 x} + \frac{d}{a_4} \quad (24)$$

C_1, C_2 and C_3 can be gained by upper boundary conditions, λ_i coefficients can be computed by the following equation as,

$$a_1\lambda^3 + a_2\lambda^2 + a_3\lambda + a_4 = 0 \quad (25)$$

Pipe Surface temperature can be gained by Eq. (22) as,

$$T_s = \frac{\rho QCp}{h_i \pi D_i}(c_1\lambda_1 e^{\lambda_1 x} + c_2\lambda_2 e^{\lambda_2 x} + c_3\lambda_3 e^{\lambda_3 x}) + c_1 e^{\lambda_1 x} + c_2 e^{\lambda_2 x} + c_3 e^{\lambda_3 x} + \frac{d}{a_4} \quad (26)$$

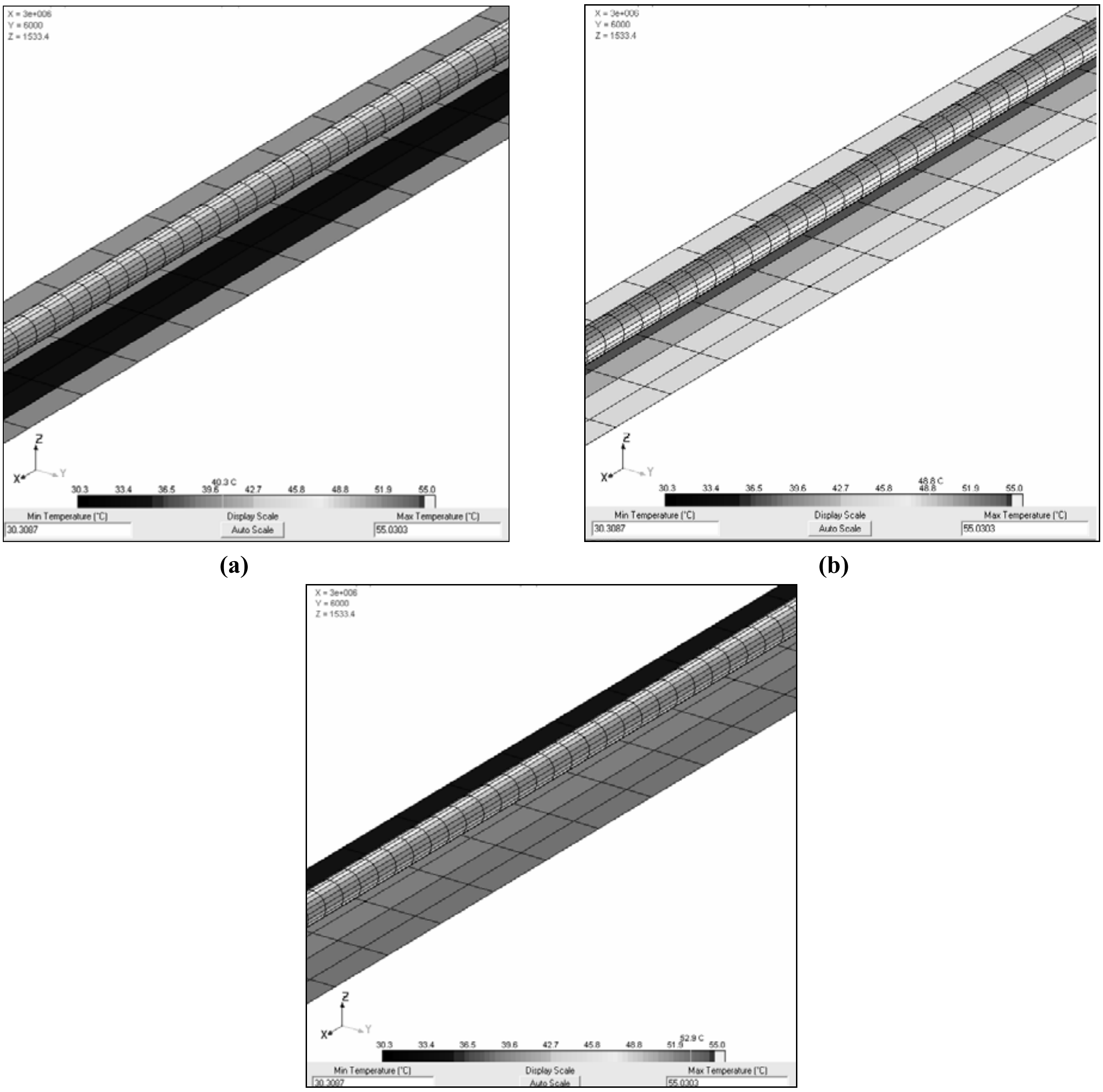
Eq. (24) and Eq. (26) are the governing equations for variations of the hourly bulk temperature and pipe surface temperature along the flow respectively, the profile is in an exponential form, however, for most practical cases, it is very close to a linear function. Hourly outlet oil temperature from the pipeline is the dominant parameter that we need. For catching this, we solved Eq. (26) at each hour of day that the sun radiates on the pipeline.

4- Numerical modeling

The numerical method has been used for catching oil temperature along the pipe flow. The study is performed at different flow rates (1000, 2000 and 3000 bbl/hr) for Kharg Island oil pipeline. The temperature of the pipe surface and fluid inside vary along the pipeline at each hour. A general-purpose commercial computational fluid dynamics package WinTherm, version 8.1 has been used for the numerical solutions. It is one of the most widely used commercial codes for simulating engineering fluid flow and heat transfer problems due to its accuracy, robustness and convenience. It can be used to model the steady state and transient distribution of heat over complex surface descriptions of component systems, WinTherm models 3-D conduction, convection, and multi-bounce radiation and it is capable of modeling sun movement correctly.

To model this condition, the same pipeline according to the geometry of the Kharg Island pipeline on Table 1 is considered. In total, 66,000 elements were needed to simulate this problem.

The temperature contours for the sections of aboveground pipeline and ground at different time (8, 12, 16 hr) is shown in Fig. 5. As shown in this figure, the upper surface of the pipe has a higher temperature at 12:00 o'clock, which is more than at any other time. At noon, sun radiates directly to the pipeline, bringing about more heat to its surface.



(a) (b) (c)

Figure 5. Temperature contours of aboveground pipeline and ground at different time of day (a) 8:00; (b) 12:00; (c) 16:00 (5th June 2008).

5- Results and discussion

Figures 6, 7 & 8 show the comparison between the numerical and mathematical results for various outlet oil temperature from the pipeline during a day. According to these figures, it is found that the results of the developed mathematical model are in good agreement with the numerical results. As is known, as oil flows through the pipeline, solar radiation is absorbed by the pipe surface and is then transmitted by conduction inward into the oil inside the space, eventually resulting in heat load to oil flow. During mid-day, the amount of solar radiation and heat load is a higher than other times; this causes a higher outlet temperature as shown in these figures.

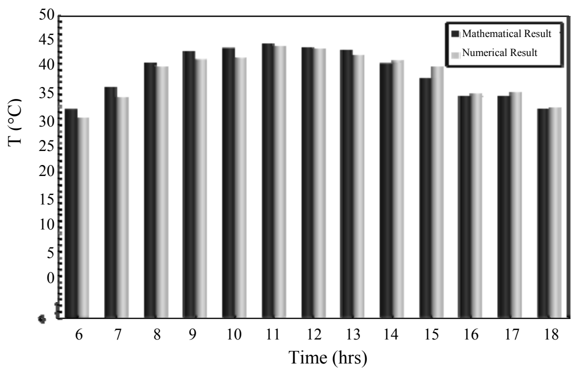


Figure 6. Mathematical and numerical result for outlet oil temperature from pipeline at 1000 barrel/hr.

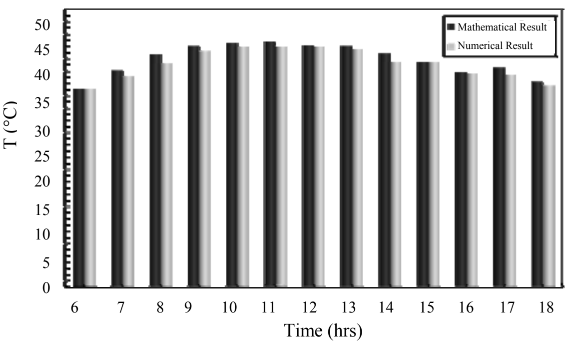


Figure 7. Mathematical and numerical result for outlet oil temperature from pipeline at 2000 barrel/hr.

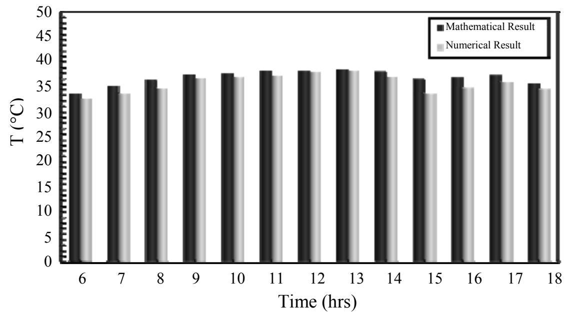


Figure 8. Mathematical and numerical result for outlet oil temperature from pipeline at 3000 barrel/hr.

The amount of solar radiation and heat load remains constant despite the flow rate. For higher flow rate, the heat load is absorbed by a larger volume of flow compared to lower flow rates. This causes the lower volume flow rate (1000 bbl/hr) oil outlet temperature to be much higher than the higher volume flow rate. The lower volume flow rate causes a higher temperature outlet than the higher outlet during the day. Figure 9 shows the effect of flow rate on outlet oil temperature for Kharg Island pipeline in a typical day. As shown, increasing the flow rate brings about a diminished outlet oil temperature for the Kharg oil pipeline.

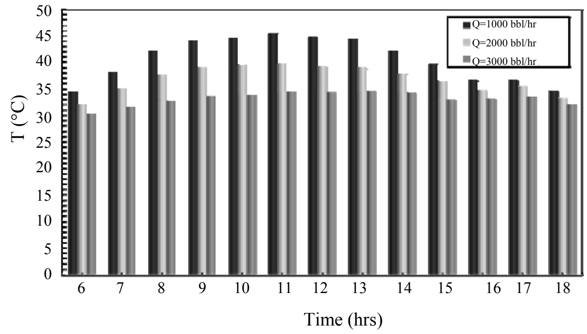


Figure 9. Effect of flow rate on outlet oil temperature from pipeline.

To verify the validity of the mathematical results, the same problem was also considered experimentally. Figure 10 shows the hourly temperature of oil pipelines in

Kharg Island that use an off-white paint color while light oil flows with 1000 bbl/hr on the 5th June 2008. We consider one of the pipelines in Fig. 2 and measure surface temperature along the flow path during a typical day and solve Eq. (26) at each hour during the day, and compare it with the result of the experimental model.

As shown, the pipe surface temperature variation along the flow path is slight. Average pipe surface temperature during the day along the pipe was measured and compared with the mathematical solution as shown in Fig. 10. Comparison between the theoretical and experimental results is considered. In this work, it is found that the results of the developed mathematical model are in agreement with the experimental results.

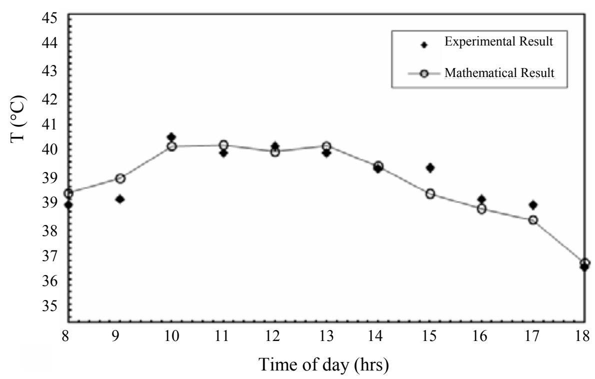


Figure 10. Hourly pipeline surface temperature on the 5th June 2008

6- Temperature effect on uncertainty of metering system

Turbine flow meter is used at the metering station of Kharg Island for measuring the volume of transferred oil. As we know, the base of buying oil in the international market is transferred volume at standard condition (1 atm and 15.5°C) (Roger C. Baker [19]). To convert the measured volume to standard condition, CTL (temperature coefficient liquid) and CPL (pressure coefficient liquid) are used. Also, it is clear that the amount of these coefficients at standard condition equal one. The exact amount of CTL is proposed from the API tables. The following equation, which was used with the metering instrument at Kharg oil terminal (Ferry [20]) is also proposed.

$$CTL' = e^{-\beta\Delta T(1+0.8\beta\Delta T)} \tag{27}$$

That,

$\Delta T = \text{observed temperature} - 60°F(15.5°C)$,

$\beta = \dfrac{613.9723}{(\rho_{standard\ condition})^2}$

CPL is constant versus temperature variations; therefore CTL is the only reason for making an error in metering. This uncertainty along with the temperature for light oil was shown in Table 3. It could be concluded that the temperature rises, while the oil volume metering increases CTL uncertainty.

Eq. (28) can be utilized for measuring the uncertainty of the oil volume measurement.

$$\text{Uncertainty} = error_{CTL} \times CPL \times V \tag{28}$$

Error uncertainty was computed by Eq. (28) according to the outlet oil temperature from the pipeline toward the metering station and CTL uncertainty in Table 3. Daily uncertainty has been estimated with the sum of hourly error uncertainty during a day. The uncertainty percent is calculated based on the following relation,

Table 3. Variation of CTL uncertainty with temperature for light oil.

T (°C)	CTL_{API}	CTL′	$\|CTL_{API}-CTL'\|$
5	1.0087	1.0088	0.0001
7.5	1.0066	1.00667	0.0001
9.5	1.0050	1.0051	0.0001
12.5	1.0027	1.0028	0.0001
15.5	1	1	0
17.7	0.9982	0.9981	0.0001
20.5	0.9959	0.9958	0.0001
22.5	0.9943	0.9942	0.0001
25	0.9922	0.9921	0.0001
27.5	0.9902	0.9900	0.0002
T (°C)	CTLAPI	CTL′	$\|CTL_{API}-CTL'\|$
30	0.9881	0.9879	0.0002
32.2	0.9860	0.9858	0.0002
33.8	0.9849	0.9846	0.0003
35	0.9839	0.9836	0.0003
37.5	0.9819	0.9816	0.0003
40	0.9798	0.9795	0.0003
42.5	0.9777	0.9774	0.0003
45	0.9756	0.9752	0.0004
47.5	0.9736	0.9732	0.0004
50	0.9715	0.9710	0.0005

$$\text{uncertainty \%} = \frac{\text{Daily Volume error}}{\text{Daily transported volume}} \times 100 \tag{29}$$

Figure 11 shows daily uncertainty percent in the metering system at Kharg oil terminal on 5th June. These data were obtained from Eq. (29) and result in Figs. 6, 7 & 8. According to Table 3, if the oil temperature during measurement is higher than standard conditions (15.5°C), uncertainty in metering will increase. The predominant result can be obtained from Fig. 11, as for greater volume flow rates the uncertainty percent is decreased.

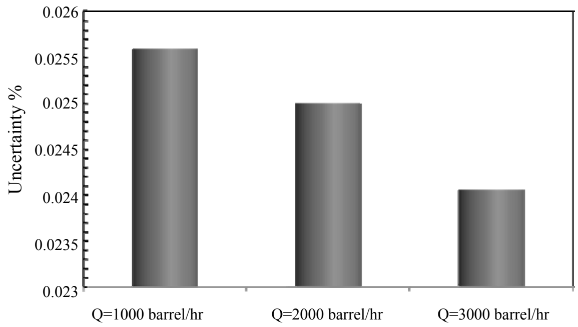


Figure 11. Daily error uncertainty

7- Conclusions

In this work a mathematical model and numerical method for temperature development in Kharg island oil pipeline in the presence of solar radiation were presented. Then, by considering the relation between temperature and uncertainty percent the following points is concluded:

(1) The results of the proposed mathematical model are in good agreement with the numerical model and experimental result of the Kharg oil pipeline.

(2) Outlet oil temperature from Kharg oil pipeline for lower volume flow rate is higher than the higher volume flow rate.

(3) Uncertainty percent is decreased when transporting oil with a higher volume flow rate, so it could be suggested to export oil in maximum allowable volume flow rate.

8- Acknowledgements

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9- Nomenclature

C_p	Specific heat of crude oil (kJ/kg K)
CPL	Coefficient of pressure liquid (dimensionless)
CTL_{API}	accurate coefficient of temperature liquid (dimensionless)
CTL'	Coefficient of temperature liquid used at metering station (dimensionless)
Di	inter diameter of pipe (m)
Do	outer diameter of pipe (m)
h_i	convection coefficient of inside pipe (w/m^2 k)
h_o	convection coefficient of air around pipe (W/m^2 K)
I	hourly solar radiation on horizontal surface (W/m^2)
I_b	beam solar radiation on horizontal surface (W/m^2)
I_d	diffuse solar radiation on horizontal surface (W/m^2)
I_o	extraterrestrial radiation on horizontal surface (W/m^2)
I_t	hourly solar radiation on horizontal pipe surface (W/m^2)
I_{sc}	solar constant (W/m^2)
K	conductivity of pipe (W/m K)
K_T	Daily average clearness index (dimensionless)
Nu	Nusselt number (= hD/k)
n	number of day of the year, starting from the first of January
Pr	Prandtel number, (=ν/α)
Q	volume flow rate of fluid inside pipe (Kg/s)
Re	Reynolds number, ($=U_{wind}D_o/\nu$)
S	Daily average daily measured sunshine duration (h)
So	Daily average maximum possible sunshine duration (h)
t	Time of day (h)
T_f	fluid temperature (°C)
T_s	pipe surface temperature (°C)
T_∞	ambient temperature (°C)
V	measured volume at oil terminal (barrel)

Greek symbols

ρ	density (Kg/m3)
ε	emissivity (dimensionless)
σ	Stefan–Boltzmann constant (5.67×10-8 W/m2 K4)
α	absorptivity (dimensionless)
ø	latitude of site (◦)
ω	solar angle (◦)
δ	solar declination angle (◦)

References

[1] Kowsary, F. and Pourshaghaghy, A., "Temperature development in pipe flow with uniform surface heat flux condition considering thermal leakage to the ambient", Energy Conversion and Management, 48:2382–2385, (2007).

[2] Yaghoubi, M., Azizian, K. and Kenary, A., "Simulation of Shiraz solar power plant for optimal assessment", Renewable Energy, 28:1985–1998m (2003).

[3] Madani, H., "The performance of a cylindrical solar water heater", Renewable Energy", 31:1751–1763, (2006).

[4] Kim, J.T., Ahn, H.T., Han, H., Kim, H.T. and Chun, W., "The performance simulation of all-glass vacuum tubes with coaxial fluid conduit", International Communications in Heat and Mass Transfer, 34:587–597, (2007).

[5] Han, H., Kim, J.T., Ahn, H.T. and Lee, S.J., "A three-dimensional performance analysis of all-glass vacuum tubes with coaxial fluid conduit", International Communications in Heat and Mass Transfer, 35: 589–596, (2008).

[6] Suehrcke, H., Peterson, E. and Selby, N., "Effect of roof solar reflectance on the building heat gain in a hot climate", Energy and Buildings, 40:2224–2235, (2008).

[7] Sahin, A.Z. and Kalyon, M., "Maintaining uniform surface temperature along pipes by insulation",

Energy, 30:637–647, (2005).

[8] Wang, X., Kendrick, C., Ogden, R. and Maxted, J., "Dynamic thermal simulation of a retail shed with solar reflective coatings", Applied Thermal Engineering 22: 637–643, (2007).

[9] Zekai, S., Solar Energy Fundamentals and Modeling Techniques. 3rd Ed., Springer, London, P. 180, (2008).

[10] Kamali, G.A. and Moradi, E., Solar radiation fundamentals and application in farms and new energy, Tehran, (2005).

[11] Cooper, P.I., "The absorption of solar radiation in solar stills, "Solar Energy, 12:333–345, (1969),.

[12] Duffie, J.A. and Beckman, W.A., Solar Engineering of Thermal Processes, Second edition, New York, Wiley, P. 133-135, (1991).

[13] ASHRAE, Handbook of Fundamentals 1979, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc, (1979).

[14] Francis, W.H., Yik, T.M. and Chung, K.T., "A method to estimate direct and diffuse radiation in Hong Kong and its accuracy", Transactions of the Hong Kong Institution of Engineers, 2:23–29, (1995).

[15] McQuiston, F.C. and Spitler, J.D., Cooling and Heating Load Calculation Manual, second ed., American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, (1997).

[16] Nayak, S.K. and Sandborn, V.A., "Periodic heat transfer in directly opposed free and forced convection flow", Int. J. Heat Mass Transfer, 20: 89–94, (1976).

[17] Holman, J.P., Heat transfer. 4th Ed, New York, Wiley, (1995).

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

[19] Baker, R. C., "Turbine flowmeters: II. Theoretical and experimental published information", Flow Measurement and Instrumentation, 4:123-144, (1993).

[20] Ferry, R., Volume correction factor For the Manual of Petroleum Measurement Standards, American Petroleum Institute, Washington, D. c., (1995).