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Studies on unsteady state heat transfer to petroleum crude oil

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ABSTRACT

Studies on unsteady state heat transfer to petroleum crude oil are not very common, as most of the works deal with steady state heat transfer to petroleum crudes in view of its industrial advantage during distillation of crude oil to make petroleum products. We come across the unsteady state heat transfer to petroleum crude oil in the beginning of the process of heating the crude in the distillation still. Keeping this objective in view, crude oil was obtained from an oil well at Fahood in sultanate of Oman, and it was heated in a stirred vessel which was kept in a water bath at 80°C. The unsteady state heat transfer coefficient was determined. The viscosity of the crude oil was varied by adding different quantities of commercial candle wax samples. The initial apparent viscosities of the samples were measured using Redwood viscometer. The dependence of heat transfer coefficient on viscosity was assessed, and it was found to decrease with increase in viscosity following an exponential power order of -0.3257 as $h = K(1/\mu)^{0.3257}$

KEYWORDS

Unsteady state heat transfer;
Petroleum crude oil;
Heat transfer coefficient;
Viscosity measurement;
Redwood viscometer.

INTRODUCTION

Heating of petroleum crude oilis an important unit operation in view of the fact that all the crude oil after drilling from the oil-wells is subjected to distillation by heating in stills to separate the crude into various components. Because the quantities of crude oil handled are very large, the distillation of it is carried out under steady state conditions by heating the oil in distillation stills or in separate still heaters. However, before the material is fed to distillation column for flashing, it is heated in tanks or in pipe heaters during which time unsteady state conditions prevail. Thus, unsteady state heating is always a precursor to steady state heating, since no system attains initially steady state conditions. During this period, unsteady state heating assumes significance.

Petroleum crude oils are of different varieties and grades, and their physico-chemical, thermal and rheological properties vary depending upon the geographical location of the wells and their age and various other parameters. Hence, each crude oil requires a different treatment and different heating method[1,2].

Some studies on overall heat transfer coefficient of oils in pipelines were reported by Na et al[3]. Most of these studies are related to heat transfer from pipe lines. Very little information is available on the heat transfer to crude oils in baths and stills. Most of the published information is related to heat transfer to the crude oil during its transportation through the pipes and conduits which is by both conduction and convection[4]. However, the classical methods of heat transfer can be applied as the crude oil exhibits Newtonian fluid behavior[5].

Hence, the present studies were taken up to determine the heat transfer coefficient (HTC) during unsteady state heating of crude oil in laboratory using a mechanically agitated vessel in the temperature range upto 80^o C. High temperatures were deliberately avoided to avoid explosion risks in laboratory. The effect of viscosity of crude oil on heat transfer coefficient was assessed. Since it is difficult to get different crude oils with different viscosities, the viscosity of the crude oil collected by us from Fahood oil field in Sultanate of Oman was varied by adding commercial samples of candle wax.

EXPERIMENTAL DETAILS

Materials

Experiments were performed with crude oil procured from Fahood oil field in Sultanate of Oman with the specifications of 44^o API gravity, and density of 0.825 g/ ml and specific heat of 2 kJ/kg ^{o}C. Wax candles for varying he viscosity of crude oil was procured from local market.

Experimental set up

Photograph of the experimental set up is shown in Figure 1. It consists of a 900 ml capacity stainless steel vessel (9.5 cm dia) with a flat bottom and a stirrer (propeller type) which was driven by a motor and with facility to regulate the speed. The stirring arrangement was made only to keep the contents mixed. No efforts were made to study the effect of stirring. The vessel was immersed in a constant temperature water bath heated by an electrical heater with thermostatic controller.

Experimental procedure

(a) Viscosity measurement

The viscosity of the crude oil was measured using Redwood viscometer by noting down the time taken in seconds for 50 ml sample to flow through the orifice. The kinematic viscosity in stokes is given by:

$$\nu = 0.0026 \times t - \frac{1.175}{t} \quad (1)$$

where t = time in seconds for 50 ml sample to flow
ν = kinematic viscosity in stokes (cm^2/s).; ν was later converted into absolute viscosity in Pa s by multiplying V with density (ρ)

The viscosity of the crude was varied by adding commercial candle wax. The data related to viscosity measurements were shown in TABLE 1.

(b) Heat transfer studies

Known volume of the sample (approximately 630 ml) was taken in the SS vessel. The contents were well mixed. The temperature of the water bath was maintained constant (T_S) at 80^{o}C with thermostatic controller. The temperature of the crude oil was quickly measured using a digital thermometer with time until the temperature reached upto 72^{o}C. The unsteady state heat transfer coefficient (h) was calculated by[6]:

$$\ln\frac{Ts - To}{Ts - T} = \frac{h\,A\,t}{\rho V Cp} \quad (2)$$

Where T_S : bath temperature; T_o : initial temperature; T : temperature at any time; t : time, s; ρ : density of liquid, kg/ m^3; V : volume of liquid, m3; C_p : specific heat of crude oil, kJ/kg ^{o}C; h : heat transfer coefficient, kW/ m^2 ^{o}C; A : heat transfer area, m^2

For each experiment, graphs were drawn between $\ln\frac{Ts - To}{Ts - T}$ and t as the best fit, and the slopes were measured.

$$\text{Slope} = \frac{hA}{\rho V Cp} \quad (3)$$

TABLE 1 : Amount of wax added vs viscosity data

Expt No.	Amt of wax added (g)	Time for flow, t (s)	Kinematic viscosity, ν (cm^2/s).	μ (Pa s)
1	0	418	1.084	0.0894
2	1	572	1.607	0.1326
3	3	743	1.930	0.1592
4	7	1597	4.152	0.3424
5	9	1987	5.163	0.426
6	10	2110	5.485	0.4524
7	11	2440	6.343	0.5232

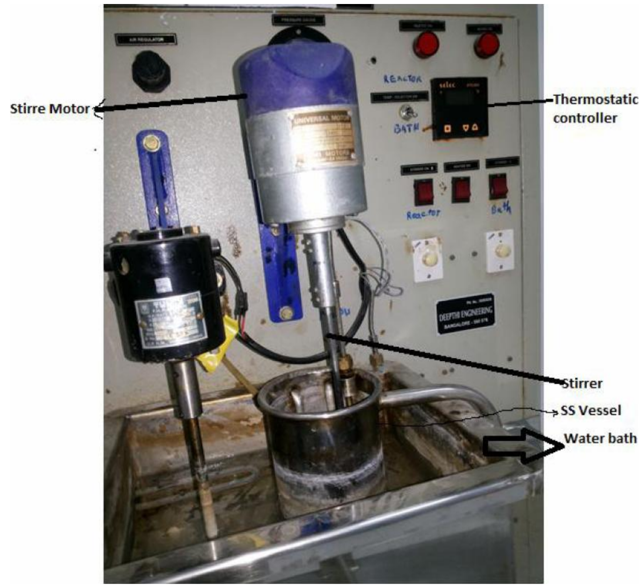

Figure 1 : Experimental set-up

The heat transfer area was determined by noting down the height of the liquid in vessel from the volume of the liquid and cross sectional area of the vessel:

$$H = \frac{4V}{\pi d2}$$

where d : dia of the vessel, m.

The heat transfer area (A) was calculated taking into consideration the bottom area plus the circumference of the vessel upto the liquid height. Thus

$$A = \frac{\pi}{4} d^2 + \pi \; dH \qquad (4)$$

RESULTS AND DISCUSSION

Experiments were mainly conducted to evaluate heat transfer coefficient (HTC) by Eq (3). The water bath temperature was maintained at 80°C which was also taken as the surface temperature of the vessel (T_s). Time vs temperature data were collected. From the experimental data, the HTC was calculated by measuring the slopes of the straight line plots ofEq (3). The data of experiment No 1 were shown in Figure 2

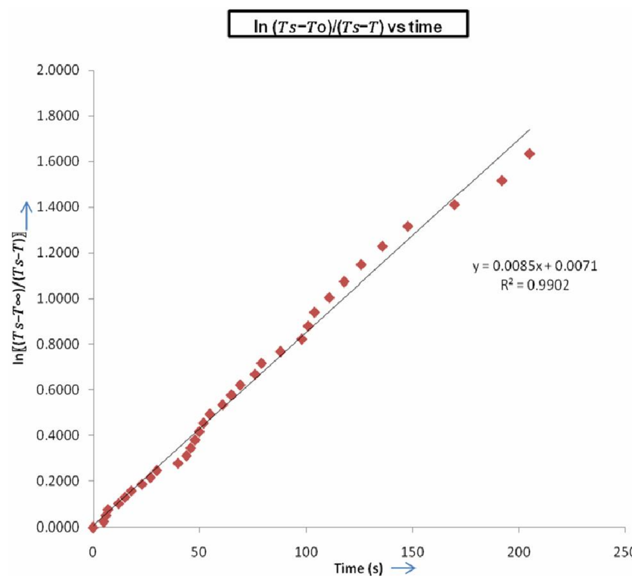

Figure 2 : Typical data of Expt 1

TABLE 2 : Experimental data of various runs

Expt No.	Crude oil Wt, M (kg)	Heat Tr. Area, A (m^2)	Slope $\frac{hA}{M\,Cp}$	µ, Pa s	HTC (h), (kW/m^2)	ln(1/ µ)	ln (h)
1	0.774	4.29×10^{-2}	9.089×10^{-3}	0.0894	0.382	2.414	-1.115
2	0.579	3.66×10^{-2}	9.197×10^{-3}	0.1326	0.291	2.0204	-1.234
3	0.571	3.62×10^{-2}	8.780×10^{-3}	0.1592	0.277	1.1873	-1.284
4	0.578	3.66×10^{-2}	6.706×10^{-3}	0.3424	0.212	1.0718	-1.552
5	0.60	3.77×10^{-2}	6.253×10^{-3}	0.426	0.199	0.8533	-1.612
6	0.629	3.92×10^{-2}	6.014×10^{-3}	0.4524	0.193	0.7932	-1.645
7	0.560	3.57×10^{-2}	5.960×10^{-3}	0.5232	0.187	0.6478	1.677

as typical data. Similarly the HTC for all experimental runs were calculated and tabulated in TABLE 2. The effect of viscosity on HTC can be represented by *Dittus–Boelterequation*[7] which adequately represents the turbulent heattransfer during flow through pipes using Nusselt Number (N_{Nu}), Reynolds Number(N_{Re}) and Prandtl number (N_{Pr}). However the same was modified by Chilton[8] for heat transfer in case of agitated jacketed vessels using impeller Reynolds Number (N_{Rei}) in place of Reynolds Number (N_{Re})as follows :

$$N_{Nu} = 0.36\ (N_{Rei})^{0.67}\ (N_{Pr})^{0.33} \quad (5)$$

Where, N_{Nu}=hd/k; $N_{Rei} = N\ d^2\rho\ /\mu$; $N_{Pr} = C_p\mu\ /k$ in which ρ and k stand for density and thermal conductivity of the fluid and N is the stirrer speed in rps. The Eq (5) can be written simply as :

$$h = Ḱ\ (1/\ \mu)^{0.33} \quad (6)$$

The above equation can be linearizedas :

$$\ln (h) = \ln (Ḱ) + 0.33 \ln (1/\mu) \quad (7)$$

The data for above equation were tabulated in Table 2, and plotted in Figure 3. The slope of the line was noted to be 0.3257 which is close to the exponent of Eq (6), and written as

$$h = Ḱ\ (1/\ \mu)^{0.3257} \quad (8)$$

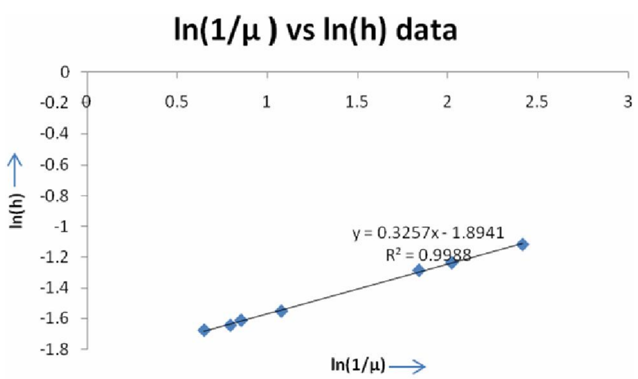

Figure 3 : Data of Eq (7)

CONCLUSIONS

The main objective of the present work was to evaluate heat transfer coefficients in case of unsteady state heat transfer process of the petroleum crude oil. Most of the published information relates to the steady state heat transfer, but the unsteady state heat transfer is always the prelude to steady state heat transfer, and assumes significance. Hence the present work was undertaken. The effect of viscosity on HTC was assessed; and the HTC was found to vary as -0.3257vbexponent of viscosity. This is in agreement with the classical studies on heat transfer in mechanically agitated vessels.

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