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RHEOLOGICAL BEHAVIOR OF HIGH VISCOSITY SAUDI CRUDE OIL

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ABSTRACT :

Some Saudi crude oils are characterized by their high viscosity and low API gravity. The wide changes in temperature during summer and winter in Saudi Arabia may cause changes in the crude oil properties. Since crude oil behavior has a significant importance for pipeline design calculations and storage, rheological behavior of Wafra heavy crude oil was determined. The results indicated that the behavior of Wafra crude oil was non-Newtonian (dilatant) and the change in crude oil viscosity with time indicates time-dependent behavior (thixotropic). Viscosity-temperature relationships were also studied. The results indicated that Dean and Lane viscosity-temperature correlation was representative of the data obtained experimentally with high accuracy.

1. Introduction

Identification of the rheological behavior of curde oil is needed for proper design of pipelines, storage and handling. Crude oil behavior may be changed from Newtonian at high temperatures, above room temperature to non-Newtonian at low temperatures, due to the existence of suspended solid particles such as paraffin, asphalt and other compounds [1].

Some of Saudi crude oils are characterized by their high viscosity and low API gravity. At low temperatures crude oil losses its flowability and displays conditional freezing. Thus improving flow behavior of these crudes by heating is required to be handled in pipelines.

The aim, of this work was to indentify the rheological behavior of Wafra high viscosity Saudi crude oil at different temperatures. Different correlations were also applied to investigate the variation in viscosity with temperatures.

2. Literature Review

Fluids are classified according to their rheological properties into Newtonian and non-Newtonian fluids as presented in the following equation [1, 2] :

$$\tau = k\gamma^n \qquad \text{... (1)}$$

With pressure and temperature held constant, a Newtonian fluid will exhibit a direct proportionality between applied shear strees and shear rate. The logarithmically plotting of shear strees-shear rate relationship shows straight line of unity slope, its intercepts as shear rate equal unity is the viscosity.

All fluids which do not exhibit a direct proportionality between shear stress and shear rate at constant temperature and pressure are classified as non-Newtonian. The most common non-Newtonian crude types are pseudoplastic, dilatnat, Bingham plastics and thixotropic [1-5].

Preudoplastic are fluids whose apparent viscosity decreases with increasing values of shear stress, power-law equation is used for calculations [2, 3] as presented in equation 1. When shear stress-shear rate relationsip is plotted on logarithmic coordinates, the slope of the straight line is the value of n which is less than unity.

Dilatant fluid behavior [4] is opposite to the pseudoplastic. The apparent viscosity increases as the deformation rate increases. With reference to the power-law, the flow behavior index, n, is greater than unity. The dilatancy is observed at very high concentrations of ultrafine particles in liquids [1].

Bingham Plastics [2] will not deform continuously until the applied stress exceeds the yield point. After that the shear rate will be proportional to the shear stress.

3. Experimental work

Rheological behavior of Wafra crude oil is determined by measuring the viscosity using Brookfield viscometer. Measurements were made using different speeds to detect the rheological porperties of the tested crude oil. Six hundreds milliliters of the crude oil was poured into a beaker. The spindle was attached to the viscometer spindle coupling. The assembly was then placed in water bath at dirrerent temperatures. The viscometer was leveled using the leveing screws and the bubble level. The speed with a control knob was truned to the desired constant reading, the clutch was depressed to hold the pointer and the motor was shut-off, the reading on the dial was then recorded and this reading was multiplied by the relevant factor to get viscosity in centipoise.

4. Results and Discussion

The behavior of Wafra crude oil has been carried out at temperatures 0, 5, 8, 15, 20, 25, 30, 40 and 50° C. Its viscosity was measured at dirreret temperatures and shear rates. In this study, power-law equation was used to study the rheological properties of Wafra crude oil.

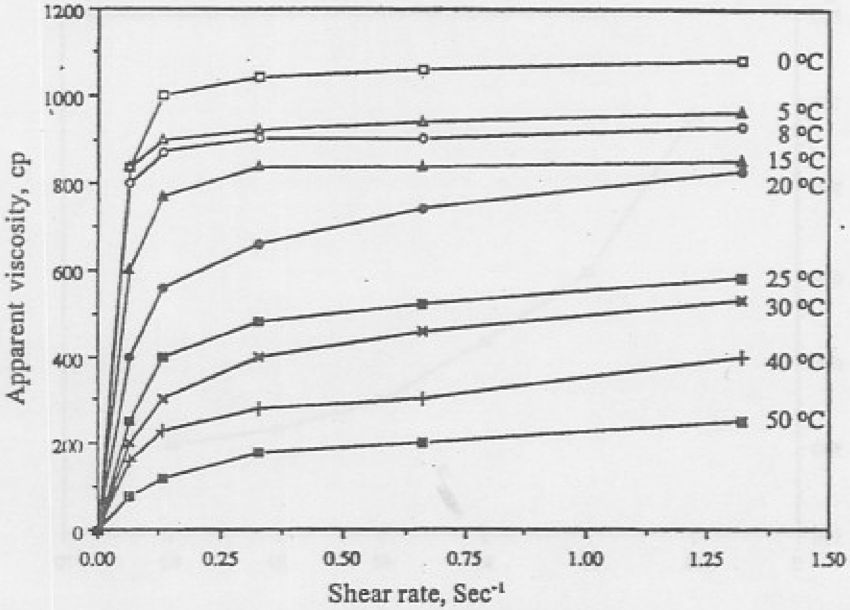

Fig. 1 Viscosity vs. shear rate of Wafra heavy crude oil at various temperatures.

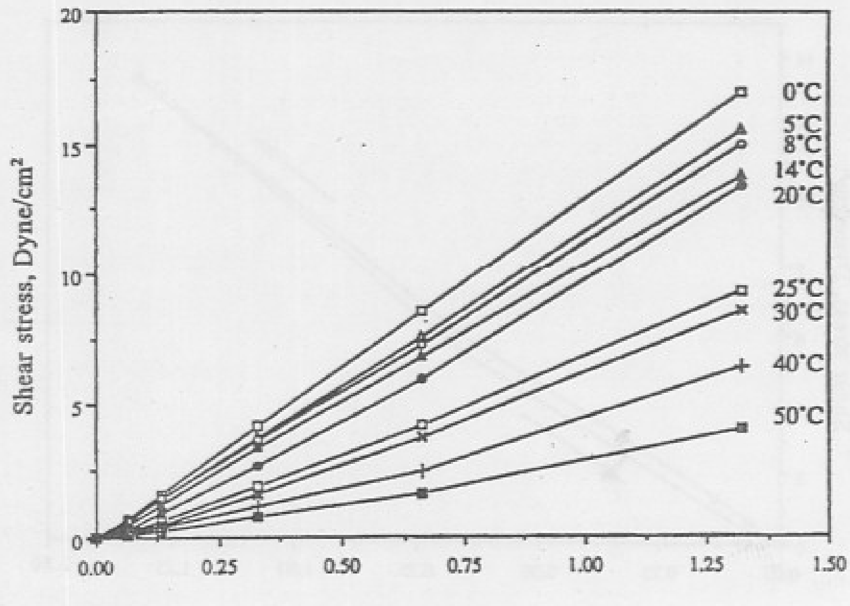

Fig. 2 Shear stress vs. shear rate of Wafra heavy crude oil at various temperatures.

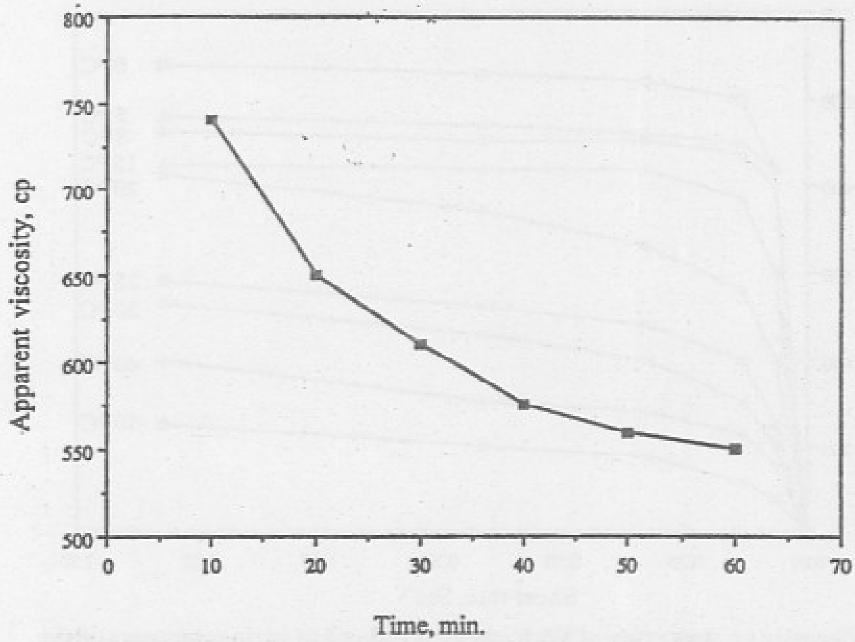

Fig. 3 Viscosity vs. time of Wafra heavy crude oil at a shear rate of 0.66 sec^{-1}.

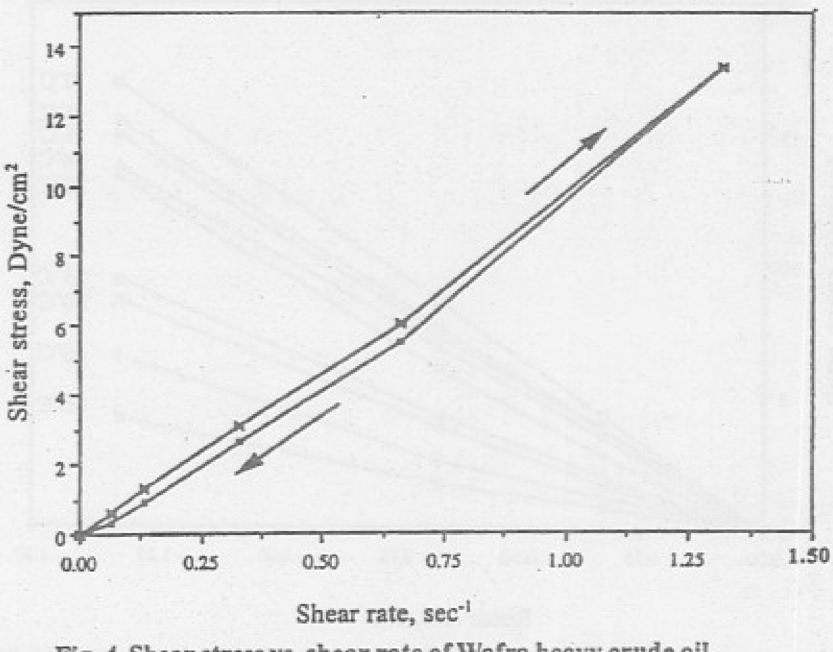

Fig. 4 Shear stress vs. shear rate of Wafra heavy crude oil.

4.1 Rheological Properties of Wafra Crude Oil

The rheological properties of Wafra crude oil were measured according to the Institute of Petroleum Standards [6] and tabulated in **table 1.** Viscosity was measured at different temperatures and shear rates. Viscosity measurements are plotted versus shear rates in **Fig. 1.** This figure shows that the viscosity of crude oil increases with increasing shear rate. This means that the viscosity of the crude oil exhibits non-Newtonian dilatant behavior. Also crude oil dilantancy was observed by plotting shear stress versus shear rates in **Fig. 2.** The curve shows concave upward increase in shear stress with increase in shear rate at different temperatures. **Fig. 3.** shows that crude oil viscosity decreases with time while it is subjected to constant shearing, therefore the fluid is time-dependent (thixotropic). When the crude oil subjected to varying rates of shear, a thixotropic behavior was also shown in **Fig. 4.** A plot of shear stress versus shear rate shows that as the shear rate was increased to a certain value then immediately decreased to the starting point, the "up" and "down" curves do not coincide. This loop is caused by the decrease in the fluid's viscosity with increasing time of shearing. The thixtropic behavior is due to the existence of paraffines, asphaltenes and resinous components in the crude oil.

Table 1. Wafra heavy crude oil properties

Property	**Numerical value**
API gravity	20.5°C
Flash point	19°C
Pour point	-45°C

4.2 Determination of Rheological Behavior Paramenters

On logarithmic coordinates, shear stress is plotted as a linear function of shear rate at various temperatures as it shown in **Fig. 5.** The slope of the straight-line (n) and the intercept value of the line on the shear stress axis where shear rate equals unity, k determine the rheological behavior of the Wafra Saudi crude oil. The values of the rheological parameters n and k were found and tabulated in **table 2.** These results show that the tested crude was non-Newtonian (dilatant) at different temperatures where n was larger than unity.

Table 2. Rheological properties of Wafra heavy crude oil

Temperature, °C	k, mPa.Sec^n	n	Type
0	15.0	1.062	Dilatant
5	12.1	1.040	Dilatant
8	12.0	1.038	Dilatant
15	11.0	1.138	Dilatant
20	09.8	1.251	Dilatant
25	08.0	1.372	Dilatant
30	07.0	1.368	Dilatant
40	04.5	1.273	Dilatant
50	02.5	1.252	Dilatant

4.3 Effect of Temperature on the Viscosity of Wafra Heavy Crude Oil

Fig. 1. shows the effect of temperature on crude oil viscosity at temperatures 0, 5, 8, 15, 20, 25, 30, 40, and 50°C. It shows that viscosity of Wafra heavy crude oil can be reduced by an average of 40% by heating from 0°C to 20°C and 74% by heating from 20°C to 50°C. For correlating the variation of viscosity with temperature, several relationships were considered. Those were Andrade [7], Herchel [8] and Dean and Lane [9] correlations.

Fig. 6. shows the variation in viscosity with temperature using Andrade correlation. When plotting log viscosity (μ) versus 1/T, a linear correlation was obtained. The following correlation between μ and T was obtained :

$$\mu = 0.025162e^{1282.1/T} \quad \text{... (2)}$$

Fig. 7. shows the variation in viscosity with temperature using Herchel [8] correlation. When plotting log μ versus log t, a linear correlation was obtained for the crude oil and the following correlation between μ and t was obtained :

$$\mu = 3.5449e^{-0.63182} \quad \text{... (3)}$$

Fig. 8. shows the variation in viscosity with temperature using Dean and Lane correlation. When plotting the reciprocal of kinematic viscosities versus temperature, the correlation holds and the following equation was obtained :

$$K = [0.096997 - 0.0017121\, t + 0.0001801\, t^2]^{-1} \qquad \text{... (4)}$$

When the correlation coefficient for the representation of experiemental data obtained by the application of Andrade [7], Herchel [8] and Dean and Lane [9] correlations, Dean and Lane correlation provided excellent match for the experimental date with a very good degree of confidence.

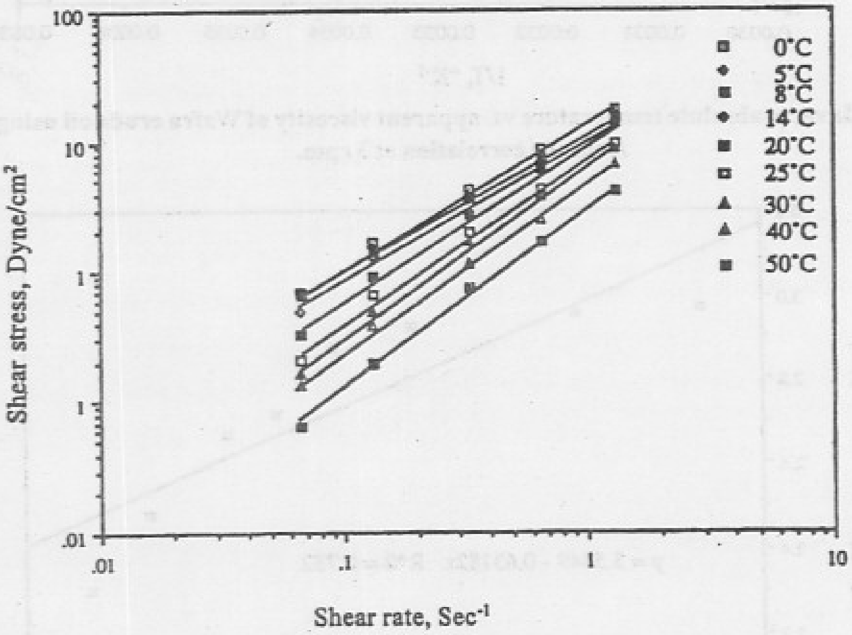

Fig. 5 Shear stress vs. shear rate of Wafra heavy crude oil at various temperatures.

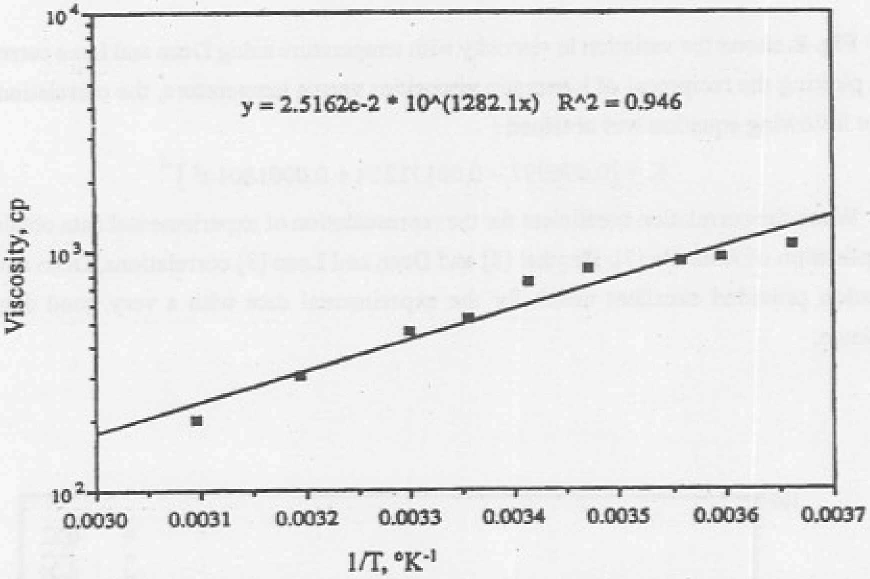

Fig. 6 Inverse absolute temperature vs. apparent viscosity of Wafra crude oil using Andrade correlation at 3 rpm.

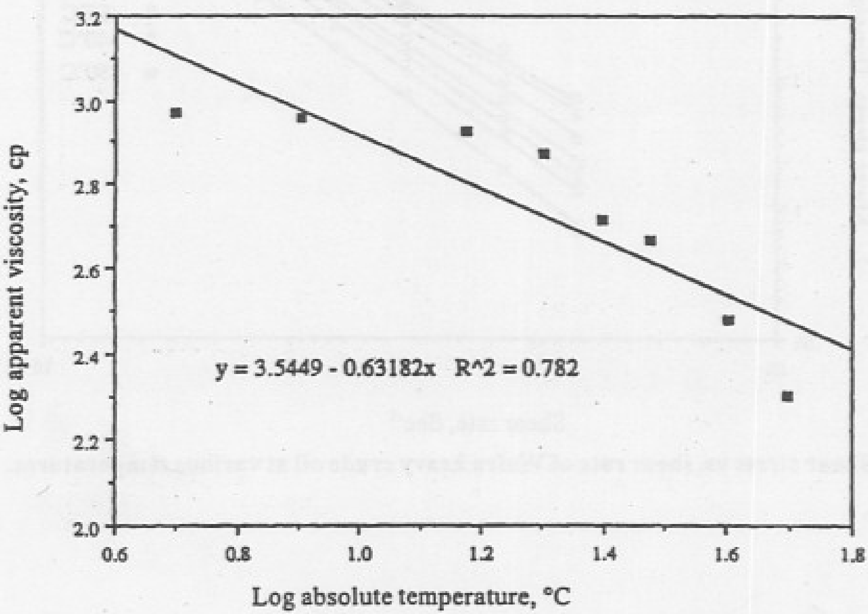

Fig. 7 Variation of viscosity of Wafra heavy crude oil with temperature using Herchel correlation at 3 rpm.

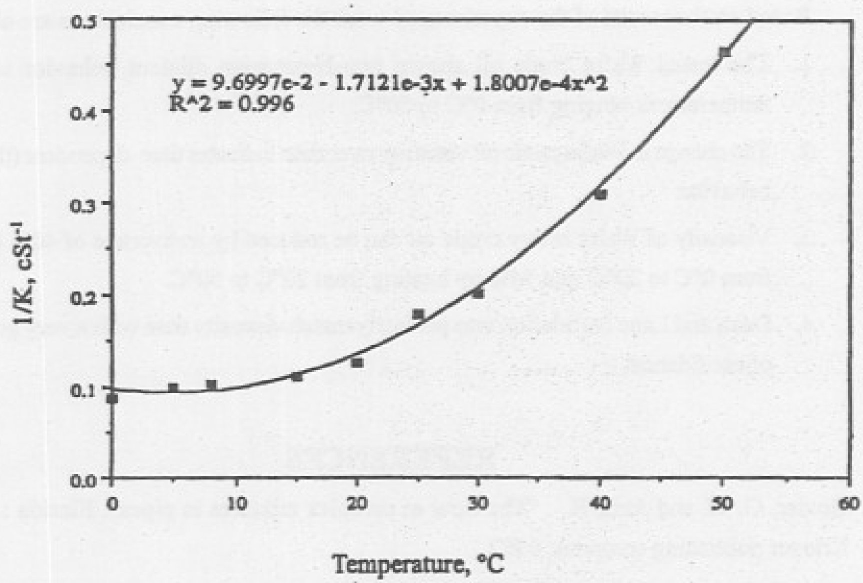

Fig. 8 Temperature vs. inverse kinematic viscosity of Wafra heavy crude oil using Dean and Lane correlation at 3 rpm.

5. Nomenclature

K	=	Kinematic viscosity, cSt.
k	=	Consistency index, $mPa.Sec^n$.
T	=	Absolute temperature, °K.
t	=	Temperature, °C.
n	=	Flow behavior index.
γ	=	Shear rate, Sec^{-1}.
τ	=	Shear stress, mPa.
μ	=	Apparent viscosity, cp.

6. Conclusions

Based on the results of the experimental work the following conclusions are obtained :

1. The tested Wafra crude oil shown non-Newtonian dilatant behavior at different temperatures ranging from 0°C to 50°C.
2. The change in Wafra crude oil viscosity over time indicates time-dependent (thixotropic) behavior.
3. Viscosity of Wafra heavy crude oil can be reduced by an average of 40% by heating from 0°C to 20°C and 74% by heating from 20°C to 50°C.
4. Dean and Lane correlation was perfectly match viscosity data with a very good degree of confidence.

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