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A Comparative investigation on Viscosity Reduction of Heavy Crude Oil Using Organic Solvents

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Abstract— **The transport of heavy crude oil from the head-well to the refinery plants is an attractive factor as its production is currently increasing around the world. Though the higher viscosity increases trouble in the piping transportation and production from the reservoir, for these reasons, this study focuses on the dilution method to reduce its viscosity using toluene, dimethyl ketone (DMK) and a mixture of (50/50 vol. %) toluene/dimethyl ketone as a dilutes solvents with different weight fraction (0, 5, 10 and 15 wt. %) at 298.15 K. The heavy oil used collected from Amara oil field, south of Iraq. The viscosity was measured by Brookfield viscometer over a range of shear rates (0 - 42s^{-1}). On another way to understand the effect of temperature, the better result for weight fraction of solvents in viscosity reduction of heavy oil was investigated under different temperatures (298.15, 308.15 and 318.15 K). The obtained results showed dilution of heavy oil samples with toluene, DMK and a mixture of (50/50 vol. %) toluene and DMK is an effective method for reducing the viscosity. Moreover, the temperature has a significant effect on the degree of viscosity reduction in the presence of the diluents. However, the higher DVR was noticed about 87.17 % at 15 wt.% of the mixture (50/50 vol. %) toluene + DMK at 318.15 K and shear rate 42 s^{-1}. Tthe relevant results attribute to an aromatic characteristic of toluene which allows interferes in the asphaltene aggregation.**

Keywords— **heavy oil; dilution; viscosity reduction; temperature; shear rate.**

I. INTRODUCTION

Globally, crude oil represents the most traded products, its prices change based on demand, at the last years, the global oil demand has increased; as a result, increasing in a people population that be used in a different domestic and industrial applications [1], [2]. The crude oil is a mixture of a lots compound with different functional groups of hydrocarbons; this difference in composition makes it possesses a different characteristic. The characteristics of crude oil depend on the content form, such as saturated, aromatic, resins, and asphaltene [3]. Separations of these contents are based on the polarization using organic diluents with various polarities or by adsorbent material has active groups [4].

Heavy oil refers to oil has (API< 20) with viscosity more than 100 cP, increases its difficulty in the piping transportation and production from the reservoir [5], [6]. On account of the increasing an energy requirement and lowering of light and medium crude oil production across the world, the attention toward heavy and extra crude oil has been increased, the viscosity of heavy crude oil increased as a result of increasing of salt, sulfur, heavy metals, wax and asphaltene in its composition [7], [8]. Various methods reported in the literature for enhancing the mobility of heavy oil [2], [9]-[11]. Dilution with the solvent represents an efficient technique in viscosity reduction [12], [13]. The reduction in viscosity has a decisive advantage that is avoiding of increases in the pressure drop and reducing a pumping cost, moreover helping the steps of dehydration and desalting in a downstream treatment process [14].

Recently, many studies focus on a dilution method using a different solvent in order to achieve a certain viscosity, Nourozieh et al [15], observed the adding a minimum quantity of n-hexane to Athabasca bitumen under different temperatures and pressures improve its mobility and has a significant effect on viscosity reduction, Popoola et al [16], reported the addition of (0.05 to 5%) from Triethanolamine (TEA) to Niger-Delta heavy crude oil at different temperature (28-65 °C) has significant effect on the reduction of viscosity and pour point, Mortazavi-Maneshand Shaw [17], showed the mixture of (toluene + butanone) addition with a ratio (50/50 vol. %) under different temperatures (-15 to 60 °C) is the best solvent for decreasing the thixotropic effect and viscosity reduction in comparison with toluene and n-heptane alone,

Narro et al [18], investigated the impact of light hydrocarbons addition products from waste plastics on viscosity reduction of heavy crude oil, they found the viscosity was reduced 90% by added 20 vol.% of light hydrocarbon at ambient temperature Mozaffari et al. [19], conducted a wide-ranging study on the relationship between the bitumen viscosity and the aggregation of asphaltene, they showed that blend of heavy crude oil with heptane and Hepatol decrease the viscosity that attributed to precipitated of asphaltene aggregation will lead to decrease it content in the mixture,

Bassane et al [20], investigated the effect of temperature and condensed gas addition on the viscosity reduction of different types of Brazilian heavy oils has API from (13.7 - 21.6), they observed that a high temperature over 20 ° C led to 70 to 77% reduction in viscosity, While, at 32 vol.% addition of condensate gas has a high impact on the viscosity reduction was about 98%, Rahimi et al.[8], study the effect of dilution with light hydrocarbons (5-15 vol.%) on extra heavy crude under irradiated used ultrasonic for (5-20)minutes at various temperatures, they found the best reduction in viscosity at 10 minutes.

However, literature concerned on a study the effect of toluene, dimethyl ketone and a mixture of toluene and dimethyl ketone as dilutes solvents on the viscosity reduction of heavy oil seems to be scarce. Consequently, in this study, the different fraction of toluene, dimethyl ketone, and a mixture of (50/50 vol. %) toluene and dimethyl ketone were chosen as dilutes solvents to conduct a comparative experimental investigation of its effects on the viscosity reduction of heavy crude oil.

II. MATERIAL AND METHODS

A. Materials

The heavy crude oil used in this study was collected from Amara oil field, south of Iraq, the API, density, and viscosity of this oil are 16, 0.979 g/cm^3 and 135.6 cP respectively at 25 ˚C. The toluene (purity = 99.8%) and Dimethyl ketone (DMK) (purity = 99.9%) were purchased from a local market supplied by Sigma-Aldrich. The diluents solvents toluene and Dimethyl ketone were used as received, and the prepared mixture from 50/50 volume percentage of toluene with dimethyl ketone was also used as a diluent's solvent.

B. Methodology

The binary mixtures of heavy crude oil with different concentrations of solvents were mixed in a closed beaker size 125 ml. The beaker was placed on a magnetic stirrer for at least an hour to confirm a homogenous mixing [17]. The viscosity measurements were conducted in a shear rate range 2- 42 s^{-1} using Brookfield viscometer (USA) model DV-11, which is a programmable rheometer complete with a temperature sensor and controlled by a computer. The rheological parameters were firstly measured at 25°C. The above sequences were carried out for higher crude oil viscosity reduction with an optimum weight percentage of solvents 15 wt.% at different temperatures 298.15, 308.15 and 318.15 K.

III. RESULT AND DISCUSSION

Dilution with solvent and temperature are two vital interactive parameters controlling crude oil viscosity. In this respect, a comprehensive discussion of each parameter has been presented in the following sections.

A. Effect of Solvent

Dilution by lighter hydrocarbons is one of the first and favored approaches was used for reducing the viscosity of heavy crude oils [21]. The viscosity measurement as a function of shear rate for binary mixtures of heavy oil from the Amara oil field with different diluents was tested at atmospheric pressure and temperature 298.15 K. The toluene, DMK and a mixture of 50/50 vol. % toluene/DMK were used as diluents with a different weight percentage of 0, 5, 10 and 15 % for each one, the shear rate ramps from 2 to 42 s-1 were mandatory on the samples. Every sample was sheared for 2 minutes at each examined shear rate prior to isothermally viscosity measurement [17].

It was observed from the obtained results shown in Figures (1 to 3), the slight viscosity decrease for pure crude oil was happened from about (134.1 to 111.5 cP) over the shearing rate, while, the diluents solvent addition decreases the viscosity of heavy oil for all the weight percentages that were used and the higher decline was observed when 15 wt. % was used, for a mixture of toluene and DMK > toluene > DMK, it's were about 91.7 to 42.5, 100.8 to 49.79 and 101.6 to 58.79 cP respectively.

These results attribute to an aromatic characteristic of toluene which allows interferes in the asphaltene aggregation [12], a Similar trend was noted Mortazavi-Manesh and Shaw [17]. To understand the effect a different concentrations additions of diluents on heavy oil decreasing viscosity at 298.15 K, atmospheric pressure and shear rate 10 s^{-1}, the obtained results presented in Figure 4, the graph shows for all cases, the viscosity was decreased exponentially with increases the concentration of diluents from 5 to 15 wt%. However, the fewer viscosities were observed when (50/50 vol. %) toluene / DMK mixture was used, the lesser value was about 61.3 cP at 15wt. % of the mixture was added.

The experimental results show it improved DVR% with an increase in weight fraction of diluents, and maximum change in viscosity occurs at 15 wt. % for all shear rate. The highest values of DVR% were about 68.66,63.28 and 56.64% for (50/50 vol.%) toluene and DMK, toluene, DMK respectively at shear rate 42s^{-1}, constant temperature, and pressure. The reduction in viscosity attributed to the formation of structure within the diluents under a shear rate.

Ghannam et al. [23]. In the direction of comprehending the effect a different weight fraction addition on degree of reducing viscosity the tests were done at constant temperature 298.15 K, atmospheric pressure, and constant shear rate 10 s-1, the results presented in Figure 8, shows for all cases. The DVR % were increased with increases the weights fraction of diluents, however, the highest DVR% were observed when (50/50 vol. %) toluene / DMK mixture was used, the highest value was about 54.8 % at 15wt. % of the mixture was added.

The degree of viscosity reduction (DVR %) is calculated by equation (1) Quan and Xing 2019[22] for heavy oil with different weight fraction of diluents as a function of shear in a Figures (5 to7).

$$\mathrm{DVR}\ \% = \frac{\mu_i - \mu_f}{\mu_i} \times 100 \qquad (1)$$

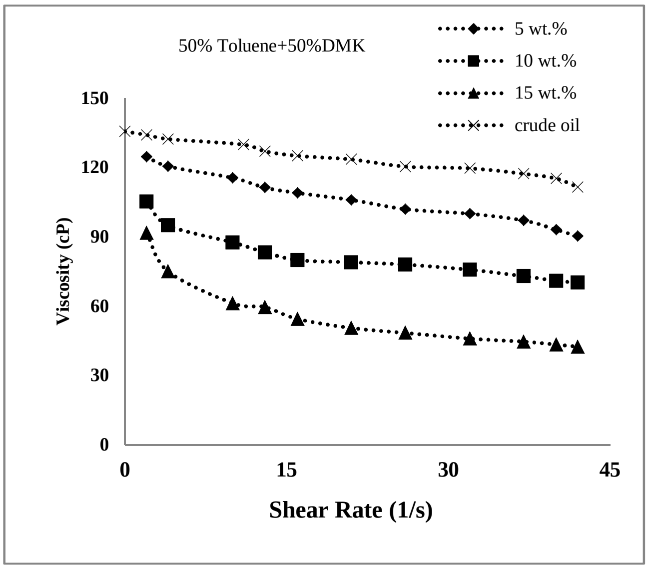

Fig.1 Viscosity of heavy oil at a different weight fraction of (50/50 vol. %) toluene / DMK

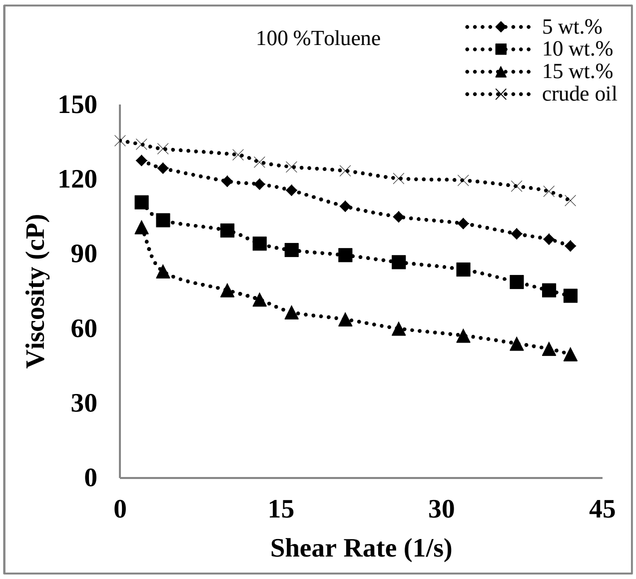

Fig.2 Viscosity of heavy oil at different weight fraction of pure toluene

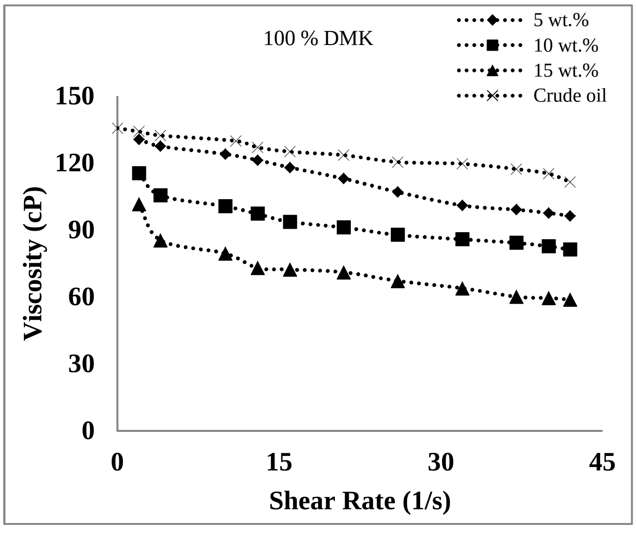

Fig.3 Viscosity of heavy oil at a different weight fraction of pure DMK

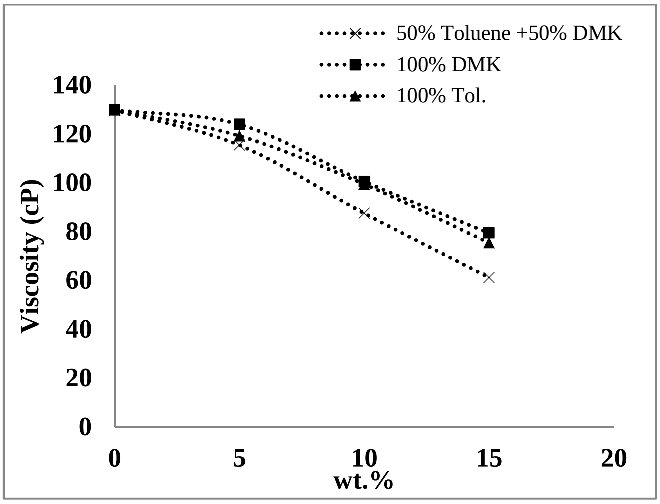

Fig.4 Viscosity of heavy oil at a different weight fraction of (50/50 vol. %) toluene / DMK mixture, pure DMK and pure toluene at a shear rate 10 s^{-1}

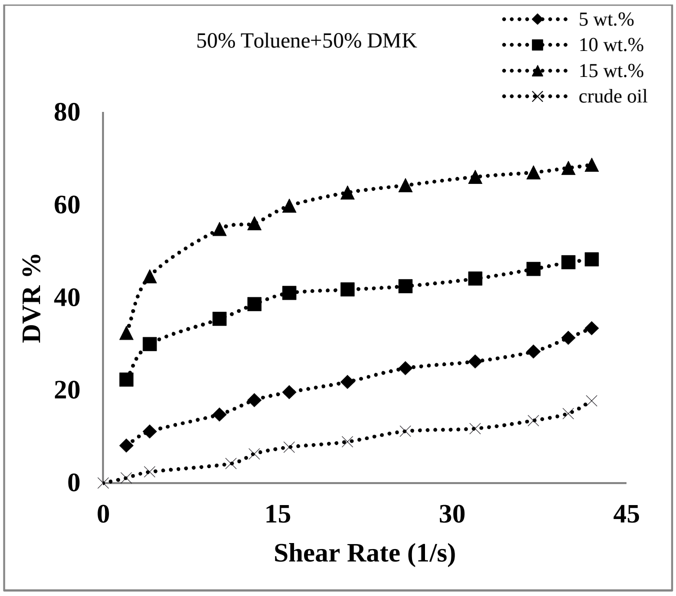

Fig.5 The degree of viscosity reduction of heavy oil at different weight fraction of (50/50 vol. %) toluene / DMK

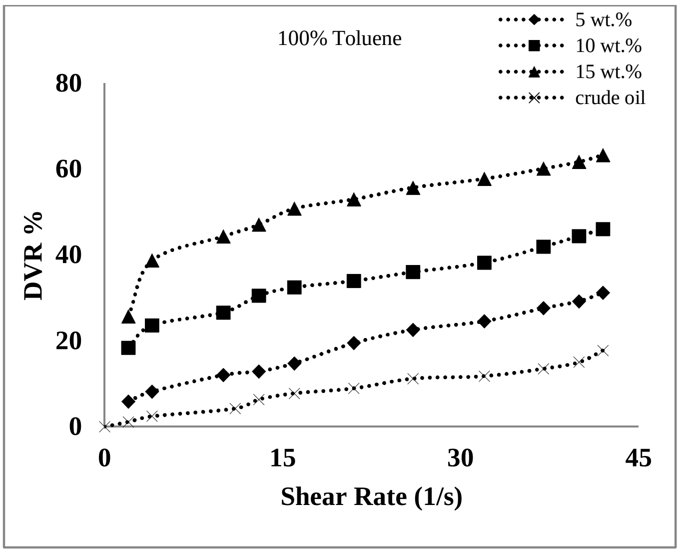

Fig.6 The degree of viscosity reduction of heavy oil at a different weight fraction of pure toluene

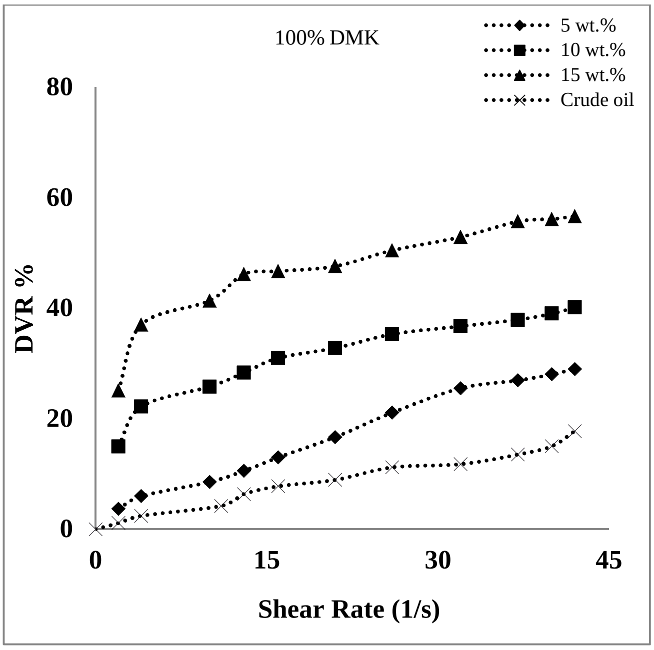

Fig.7 The degree of viscosity reduction of heavy oil at different weight fraction of pure DMK

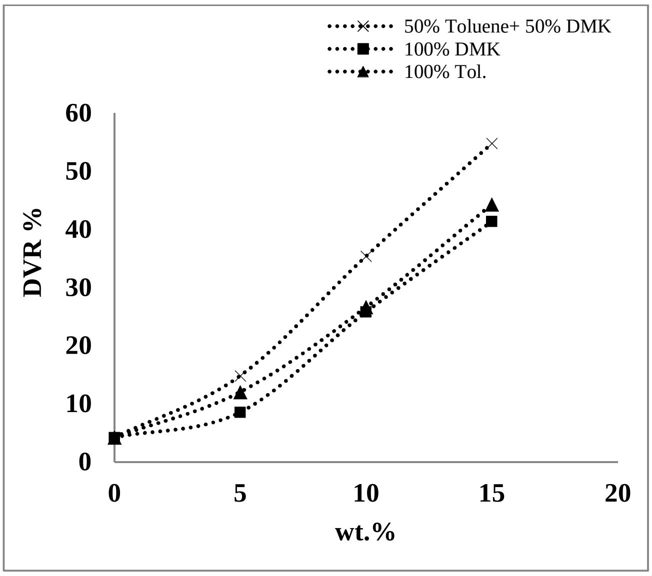

Fig. 8 The degree of viscosity reduction of heavy oil at different weight fraction of (50/50 vol. %) toluene / DMK mixture, pure DMK and pure toluene at shear rate 10 s^{-1}

B. Effect of Temperature

Figures 9 to 11 present viscosity measurement as a function of shear rate for mixtures of heavy oil from the Amara oil field and solvents over the variety of temperature (298.15, 308.15 and 318.15 K), the tests were done at atmospheric pressure and shear rate ramps from 2 to 42 s^{-1}. The toluene, DMK and a mixture of (50/50 vol. %) toluene / DMK were used as diluents with the optimum weight fraction of diluents (15 wt.%) for each one. As was noted in paragraph 3.1, every sample was sheared for 2 minutes at each examined shear rate prior to viscosity measurement [17]. The results show non-Newtonian shear fluid behavior for the shear rate less than 10 s^{-1} on which the viscosities of crude oil declined sharply with a shear rate and the Newtonian activities were observed at the shear rate range of 10-42s^{-1}.

Accordingly, could note the solvent addition reduced the viscosity of heavy oil for all temperature and the decreases is a robust role of diluents composition [24]. However, the higher decline of viscosities were observed at 318.15 K, for a mixture of toluene and DMK , toluene and DMK, it's were about (70.7 to 17.4), (77.66 to 22.77) and (82.45 to 28.39) cP respectively, these results could be recognized to thermal influence [25].

In order to understand the effect of temperature on heavy oil decreasing viscosity at a constant weight fraction of diluents (15 wt. %), atmospheric pressure and shear rate 10 s^{-1}, the obtained experimental results presented in Figure 12, for all cases, the viscosity was decreased with increases the temperature. However, the lower viscosities were about 45.30, 52.33 and 57.31 cP for toluene / DMK mixture, toluene and DMK respectively at 318.15 K.

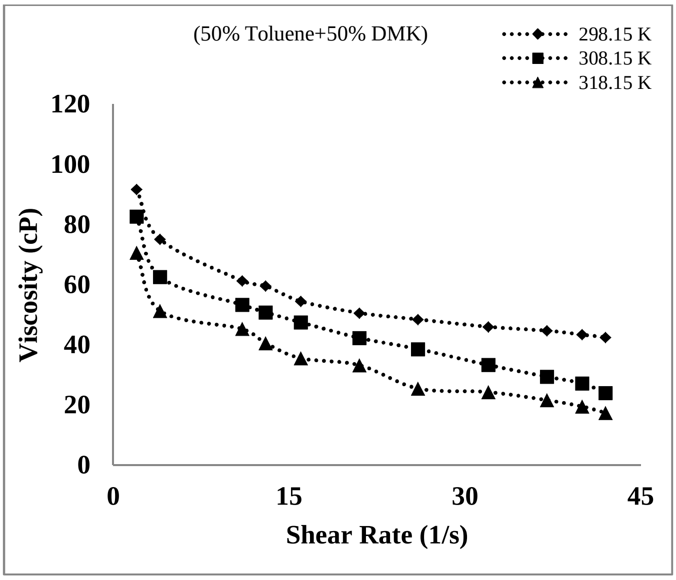

Fig. 9 Viscosity of heavy oil at 15 wt. % of (50/50 vol. %) toluene / DMK

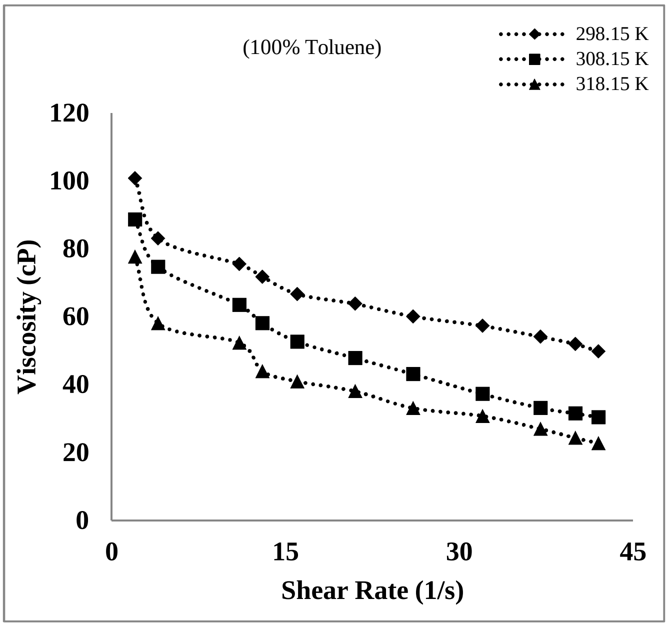

Fig.10 Viscosity of heavy oil at 15 wt. % of pure toluene

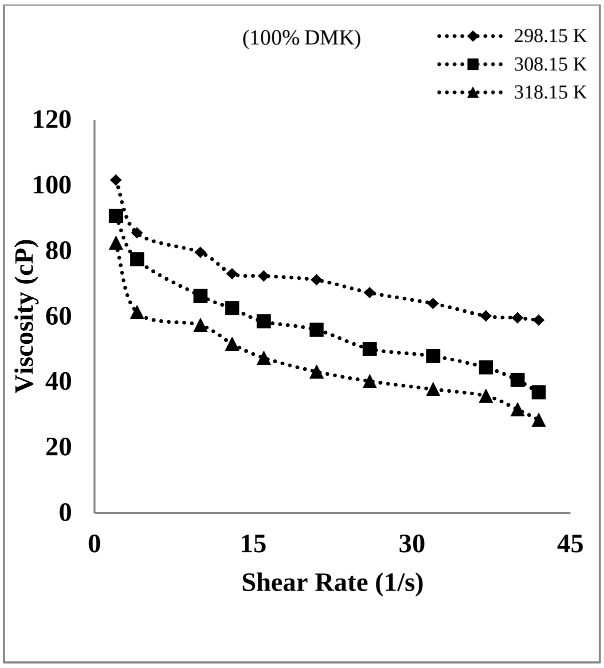

Fig. 11 Viscosity of heavy oil at 15 wt. % of pure DMK

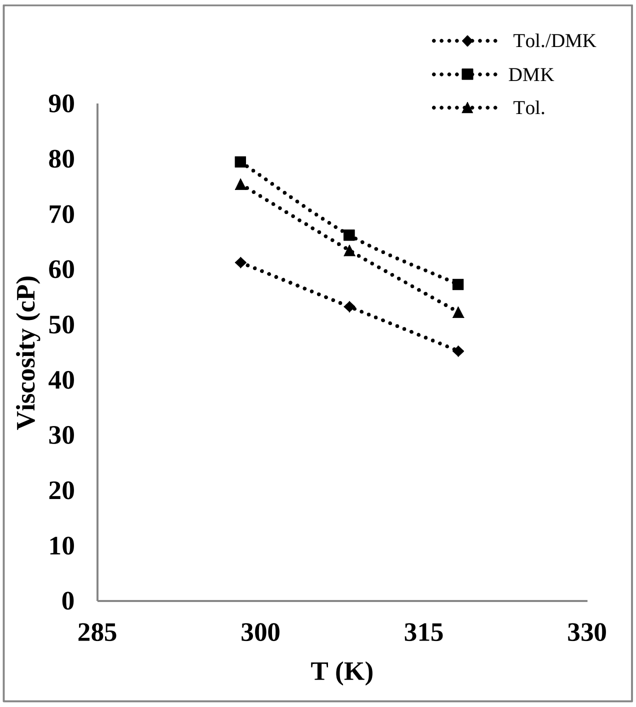

Fig.12 Viscosity of heavy oil at 15 wt. % of (50/50 vol. %) toluene / DMK mixture, pure DMK and pure toluene at different temperature and shear rate 10 s^{-1}

So, to estimate the effect of temperature, the DVR% for heavy oil with a range of temperature was plotted as a function of shear rate (2-42 s^{-1}) as shown in Figures (13 to 15), results revealed that maximum reduction viscosity happens at 318.15. In the way of understanding the effect of temperature on DVR%, tests were done at a constant weight fraction of diluents (15 wt. %) and shear rate 10 s^{-1}, the results obtained presented in Figure 16, shows the DVR % were increased with increases the temperature and the greatest was about 66.6 % at 318.15 K for oil / toluene +DMK mixture.

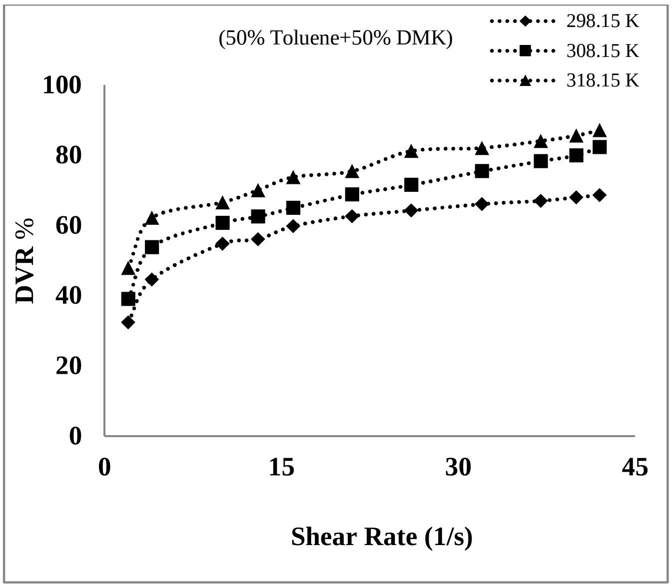

Fig. 13 The degree of viscosity reduction of heavy oil at 15 wt. % of (50/50 vol. %) toluene / DM

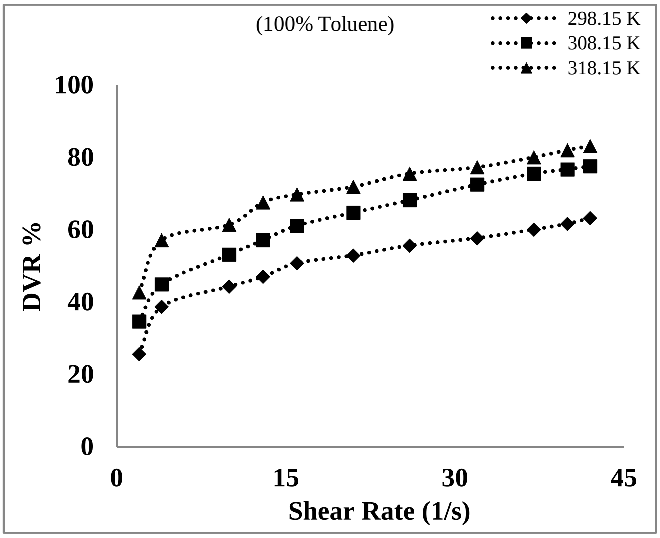

Fig. 14 The degree of viscosity reduction of heavy oil at 15 wt. % of pure toluene.

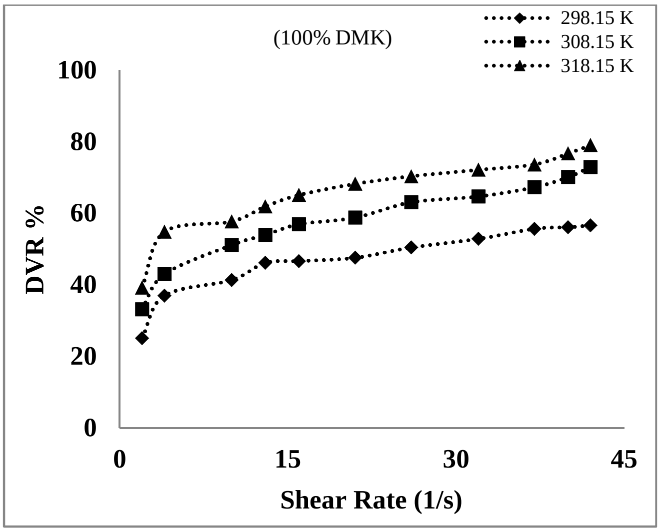

Fig. 15 The degree of viscosity reduction of heavy oil at 15 wt. % of dimethyl ketone

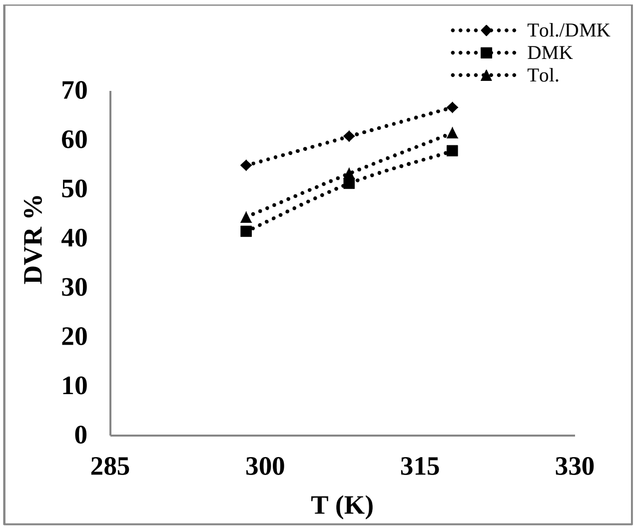

Fig. 16 The degree of viscosity reduction of heavy oil at 15 wt. % of (50/50 vol. %) toluene / DMK mixture, pure DMK and pure toluene at different temperature and shear rate 10 s^{-1}

IV. CONCLUSIONS

The obtained experimental results offering the useful aspect of this technique in the petroleum industries sector for easing oil transportation over pipelines. The following conclusions can be drawn from the attained results. The addition of different weight fraction of solvents toluene, DMK and a mixture of (50/50 vol. %) toluene / DMK to the heavy oil decreases its viscosity and increases the degree of viscosity reduction. The less viscosity and higher degree of viscosity reduction were obtained at 15 wt. % of solvents for the mixture (50/50 vol. %) toluene / DMK > toluene > DMK. Lower viscosity and the higher degree of viscosity reduction were noticed by 15 wt. % of the mixture (50/50 vol. %) toluene / DMK additions were about 42.5 cP and 68.7 % respectively at temperature 298.15 K and shear rate 42 s^{-1}. The temperature has a significant influence and increases temperature permanently dramatic decrease in oil viscosity and increases the degree of viscosity reduction. However, the best results were obtained at 318.15 K. Under the effect of temperature, the lower viscosity and higher degree of viscosity reduction were about 17.4 cP and 87.17 % respectively when 15 wt. % of the mixture (50/50 vol. %) toluene / DMK was added at temperature 318.15 K and shear rate 42 s^{-1}. Non-Newtonian behavior was observed for the shear rate less than 10 s-1 on which the viscosities of crude oil declined sharply with a shear rate and the Newtonian behavior was noticed at the shear rate range of 10-42s^{-1}.

NOMENCLATURE

API	American Petroleum Institute
wt.%	Weight Percentage
DVR%	Degree of viscosity reduction
T	Temperature
K	Greek letters
μ	Viscosity of heavy oil
cP	Subscripts
i	Before
f	After

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