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PARAMETRIC STUDY ON ELECTRICAL CONDUCTIVITY OF CRUDE OILS; BASIS EXPERIMENTAL DATA

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Abstract

The electrical conductivity of crude oil and related water-in-oil emulsion play a vital role to design internal electric field and large external transformers in the electrostatic dehydrator/desalter system. Furthermore, it determines the optimum frequency of voltage in new technologies of the high voltage power unit. First of all, the electrical conductivity of crude oil is a material parameter and differs with crude type. Furthermore, the electrical conductivity is strongly dependent on temperature and water content of w/o emulsion. These influences are all together very inconvenient for a desalter design engineer as the electrical power within an electrostatic dehydrator can differ significantly. In this work, measurements of electrical conductivity have been made for several different types of crude oils with an equipped test cell. Five different crude oils have been investigated. The measurements have been completed for five temperatures of 22, 40, 50, 60 and 70°C. It could be confirmed that there is a strong influence of the crude oil type and temperature on the electrical conductivity. Furthermore, the results illustrated that at high temperatures, there is a strong influence of water content on the electrical conductivity of w/o emulsion.

Keywords: electrical conductivity; crude oil; temperature; water content; w/o emulsion.

1. Introduction

The water content of extracted crude oil increases during a reservoir lifetime as production schemes lift more water with oil from water-drive formations and water-flooded zones. The extracted mixture is passed through the pressure relief valves; in which an emulsion of small water drops in oil is formed. The water has to be separated before the crude oil is pumped. Efficient oil-water separation is completed in the electrostatic dehydrator/desalter, in which the electric field gives rise to attractive forces between the droplets and improve the separation efficiency [1-7]. On the other hand, the electrical power used by electrostatic dehydrator is strongly dependent on the actual electrical conductivity of crude oil and related w/o emulsion at operating temperatures [8-9].

Challenges with some crude oils include higher conductivity in operating temperatures and increased w/o emulsion conductivity due to higher water cuts. Typically crude oil dehydration vessels use heat, retention time and electrostatic field [8-9]. The AC technology provides limited voltage gradients and is not efficient for treating conductive crude oils, leading to the use of very large vessels and power units, and the use of lower voltage gradients. The effect of higher crude oil conductivity in an AC treater is a lower electrostatic field, resulting in less effective dehydration and more electrical power consumption. The traditional solution is using larger power units in an AC treater and the novel technique is applying new electrostatic technologies [9].

The crude oil conductivity is very important for the function of the electric fields inside the electrostatic dehydrator. If the crude oil conductivity is very high, the electrical power consumption is increased, and the average applied voltage gradient is reduced through voltage decay [9], as illustrated in Figure 1.

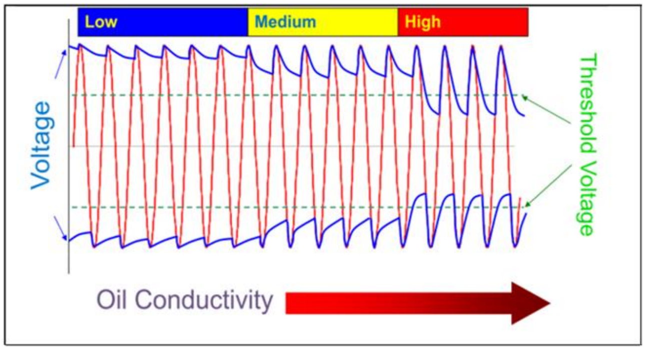

Figure 1.Voltage decay as a function of increased crude oil conductivity [9]

The electrical conductivity is measured in nano Siemens per meter (nS/m). The conductivity of the crude oil is affected by the process temperature of the crude oil treater. It can increase several times from ambient temperature to the process temperature of the electrostatic dehydrator [9]. Therefore, it is important to measure the crude oil conductivity at the operating temperature and not only at ambient temperature.

In this work, an accurate technique for measuring crude oil conductivity at elevated temperatures has been developed. Several different types of crude oils have been applied to study the effect of crude oil characteristics on the electrical conductivity. To study the effect of temperature, the measurements have been completed at some different temperatures. Furthermore, the effect of water content on the conductivity of w/o emulsion is investigated for some different water contents.

2. Experimental part

As displayed in Figure 2, a laboratory set-up consists of a high-voltage (HV) electric power supply, an accurate digital multimeter, an equipped test cell and a temperature bath has been used for the measurements. Crude oil is filled in a 100mL beaker with two parallel steel plates. After sealing its cap, the beaker is put into a temperature bath. Furthermore, in the case of w/o emulsions, it is prepared and stabilized using a high-speed laboratory homogenizer. A rectified 1 kV DC voltage is supplied by an adjustable HV transformer/rectifier. The positive and negative poles of HV output are connected to the plates of test cell passing through the multimeter in the closed circuit. The passed current is measured by the digital multimeter in microampere (μA).

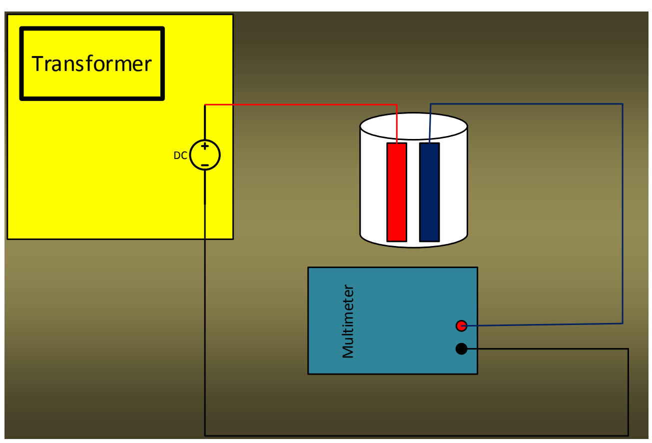

Figure 2. The laboratory set-up used for the measurement of crude oil conductivity

According to Ohm's Law (V=I.R), there is a linear relationship between the voltage, current, and resistance in a circuit. Firstly, the system is calibrated using a standard electrical resistance element for more assurance. For each crude oil at the specified temperatures, the measured current is applied to calculate the resistance. Consequently, the crude oil resistivity (ρ) and conductivity (σ) are calculated using the following equations:

$$R = \frac{V}{I} \quad (1)$$

$$R = \rho \frac{l}{A} \quad (2)$$

$$\sigma = \frac{1}{\rho} \quad (3)$$

Five different types of crude oils have been applied to study the effect of crude oil characteristics on the electrical conductivity. The selected crude oils have different API, asphaltene content, wax content, and kinematic viscosity. Specifications of the considered crude oils are presented in Table 1.

Table 1.Specifications of the considered crude oils

Crude Oil	API	Asphaltene Content (wt%)	Wax Content (wt%)	Kinematic Viscosity (c.St.)	
				@ 20°C	@ 40°C
A	33.8	1.1	4.8	11.49	6.13
B	29.7	2.6	5.9	26.48	10.4
C	24.8	7.2	4.0	47.48	21.00
D	20.0	10.0	3.7	277.1	81.63
E	18.2	10.6	3.9	1403	284.3

3. Results and Discussion

Electrical conductivities of the presented crude oils in Table 1 were measured using described experimental set-up and the procedure. To study the effect of temperature as well as crude oil characteristics, the measurements have been completed at some elevated temperatures. The results are presented in Table 2.

Table 2.Electrical Conductivity of the crude oils

Crude Oil	Temperature (°C)	Conductivity (nS/m)	Crude Oil	Temperature (°C)	Conductivity (nS/m)
A	22	56.6	D	22	6.7
	40	128.5		40	17.8
	50	208.8		50	39.7
	60	219.3		60	56.1
	70	232.7		70	79.0
B	22	94.9	E	22	14.3
	40	209.1		40	48.5
	50	391.5		50	130.8
	60	428.4		60	141.8
	70	544.2		70	162.4
C	22	50.3			
	40	93.9			
	50	167.0			
	60	188.7			
	70	216.1			

Figure 3 displays the effect of temperature on the electrical conductivity of the considered crude oils. It is illustrated that for all crude oils, the conductivity is increased with temperature up to several orders of magnitude. Furthermore, the variations are more significant under the temperature of 50 °C. The measurements also show that type of crude oil has an essential effect on the conductivity. As it could be revealed from Figure 3, the conductivity of the considered crudes may differ up to several times at the same temperature.

However, some relations may be supposed regarding Figure 3 in conjunction with crudes specifications in Table 1; but the earliest predictions like crude API are not comprehensive. It may be related to the complexity of crude oil compositions and their interactions. Therefore, it seems that a comprehensive explanation of the above differences in crude conductivities is so complex. However, one may relate different crude conductivities to the wax content.

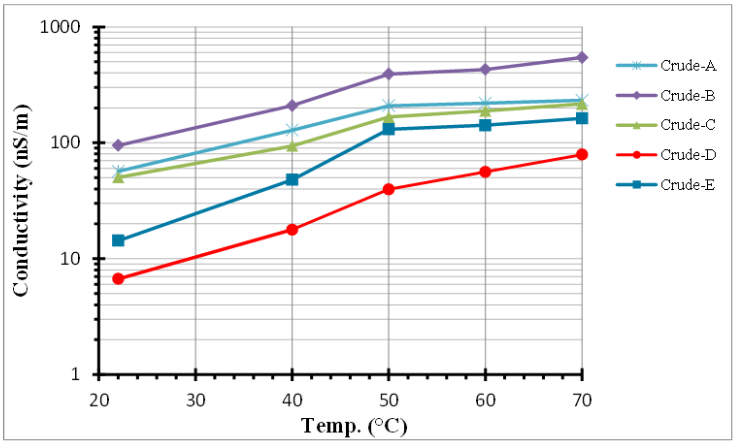

Figure 3. Electrical conductivity of the crude oils versus temperature

Figure 4 displays the effect of wax content on the electrical conductivity of the considered crude oils. It is illustrated that for all temperatures, the conductivity is increased with wax content up to several orders of magnitude. Furthermore, the variations are more significant under the wax content of 4.0 wt%. Once more, Figure 4 is illustrated that increasing of the temperature enhan-ces the oil conductivity up to several times, especially for the temperatures up to 50°C.

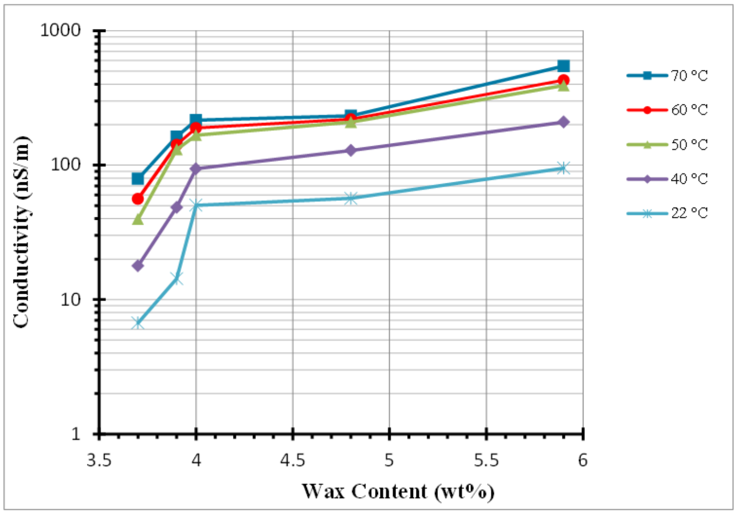

Figure 4. Electrical conductivity of the crude oils versus wax content

As it was mentioned, the most important application of the conductivity values is for the design of the electrocoalescer related equipment. On the other hand, we know that the exiting process fluid inside the electrostatic dehydrators is w/o emulsion, consisting of variable water contents dispersed in the crude oil. From this point of view, the conductivity of w/o emulsion becomes so significant.

The effect of water content on the conductivity of w/o emulsion is investigated for crude oil type "D". Several homogenized w/o emulsions were prepared with some different water contents. To study the effect of temperature as well as water content, the measurements on w/o emulsions have been completed at two temperatures of 22 and 60°C. The results are presen-ted in Table 3.

Table 3.Electrical Conductivity of w/o emulsion using crude "D"

Temperature (°C)	Water Content (vol%)	Conductivity (nS/m)
22	0	6.7
	1	9.2
	15	10.3
	30	12.8
60	0	56.1
	1	91.8
	15	144.3
	30	2295

Figure 5 displays the effect of water content on the electrical conductivity of w/o emulsions prepa-red using crude oil type "D" at two temperatures of 22 and 60°C. It is illustrated that increa-sing of the water content at temperature 22°C has no significant effect on the conductivity of w/o emulsions. This trend can be explained regarding stagnant nature of bounded water drop-lets as dispersed phase in the continuous oil phase at low temperatures. Since only the conti-nuous oil phase connects two opposite polarity plates and water droplets have not a significant movement in the oil, so water phase does not contribute to the conductivity of the emulsion. On the other hand, Figure 5 illustrates that increasing the water content at temperature 60°C has an essential effect on the conductivity of w/o emulsions. As it could be revealed from Figure 5, the conductivity of the emulsion is increased up to several orders of magnitude at temperature 60°C, especially for the water content of 30%. The above difference in trends of w/o conductivity at two temperatures of 22 and 60°C can be explained regarding the mobility of water droplets as dispersed phase in the continuous oil phase at different temperatures. At low temperatures, water droplets are bounded in the crude oil, and therefore they have not a significant movement in the oil; while at elevated temperatures, they become rather movable due to removing of some surrounding materials (like asphaltenes, etc.) and also because of reduced oil viscosity. Consequently, it is not only the continuous oil phase that connects the plates, but also water phase contributes in conductivity of the emulsion.

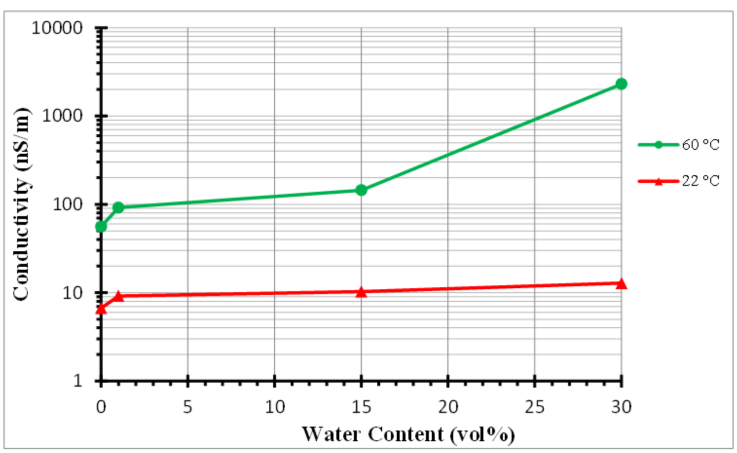

Figure 5. Electrical conductivity of w/o emulsion versus water content for crude "D"

4. Conclusions

The conductivity of crude oil and w/o emulsion is important data for the design of the electro-static dehydrators. Electrical conductivity has been measured and analyzed for five different crude oils. The results established that the electrical conductivity of crude oils strongly depends on the crude oil type and specifications. The variety of crude oil compositions and their inter-actions harden a comprehensive statement. However, the results demonstrated that the con-ductivity is increased with wax content up to several orders of magnitude, especially for the wax contents under 4 wt%. The results also confirmed that the conductivity is enhanced with temperature up to several times, especially for the temperatures under 50°C. Furthermore, the results illustrated that at high temperatures, there is a strong influence of water content on the electrical conductivity of w/o emulsion, especially for the water contents above 15 vol%.

Nomenclature

A *Area of the plate, m^2*
I *Current, A*
l *Distance between the plates, m*
R *Resistance, Ω*
V *Voltage, V*

Greeks Letters

ρ *Resistivity, Ω m*
σ *Conductivity, $(\Omega\ m)^{-1}$*

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