INTERFACIAL RHEOLOGICAL PROPERTIES OF IRAQI CRUDE OILS WATER SYSTEM

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ABSTRACT

Experience proves that, interfacial rheological properties may play a decisive role in oil displacement processes, and consequently in the efficiency of enhanced oil recovery processes.

Investigations were carried out with Iraqi crude oils, using distilled water and formation water as aqueous phase. Interfacial viscosity was determined with Contraves Low Shear 30 viscometer in rotational mode of operation at 30 oC in the shear rate range between 0.001 and 100 sec-1. The interfacial tension of oil-water systems was determined by the pendent drop method.

On the basis of experimental results it was established that there is a difference between the interfacial viscosities and tensions of the different oil-water systems. Films formed at interface have generally non-Newtonian flow behaviour, and both interfacial viscosity and deviation from Newtonian flow behaviour increase with contact time.

INTRODUCTION

The crude oil-water interface possesses very marked rheological properties. This can be demonstrated by the formation of wrinkled flim around an oil drop as its size reduced in water. These rheological characteristics play a fundamental role in the displacement processes and phase-exchange mechanism in the hydrocarbon reservoirs. One of the main purposes of chemical floodings application in enhanced oil recovery processes is to reduce these interfacial properties.

Bourgoyne et. al.[1] have shown that irreversible rigid films are formed at the crude-water interface, which may strongly influence spontaneous adsorption or displacement processes in porous media. Though this phenomenon is well known, no adequate explanation exists for flow processes when the rheological properties of the interface were not considered. Slattery[2] and Brown et. al.[3] emphatically called attention to the importance of the interfacial viscosity in the displacement mechansim.

Whiteley and Ware[4] and Widmyer et. al.[5] explains the general characteristic of low displacement efficiency due to the formation of a spontaneous emulsification and/or tight emulsions. Accordingly an excellent laboratory result of surfactant flooding could not be achieved in field application. Wasan et. al.[6], and Neustadter et. al.[7] proved that spontaneous demulsification of the emulsion, the coalescence of particles and the formation of a socalled oil bank, which is the precondition of efficient oil displacement, are to be expected only if a low interfacial tension is accompanied by a similarly low interfacial viscosity.

The rheological properties of crude oil-water interface are thus of a considerable importance to the oil industry. In this paper the interfacial rheological properties of Iraqi crude oil-water systems were investigated. The fundamental interfacial rheological properties of two crude oil having different composition and origin were studied in the presence of different compositions of aqueous phases, as a function of contact time, at different shear rates.

EXPERIMENTAL WORK

Measurements were carried out with a Contraves Low Shear 30 viscometer (shear rate changed in the 0.001 to 100 sec-1 range according to a linear program of two minutes), the edge of the biconical measuring head of which was located in the boundary layer. Measurement required approximatelly (1 cc) of each hydrocarbon and aqueous phase. The measurements of interfacial tension of oil-water systems was determined by the Pendent drop method.

For the investigation of fundamental rheological phenomena, two crude oils not solidifying at the mrasurement temperature are used. The properties of the two crude oils investigated are given in Table (1).

Table (1) Properties of the Two Crude Oil Investigated

Property	Crude A	Crude B
Character	Int. Paraffinic	Paraffinic
Sp. Gr. 15/15 °C	0.84	0.80
API gravity	36.95	45.40
Viscosity @ 30 °C, Pa.s	5.45	3.80

RESULTS AND DISCUSSION

Active compounds at the water-oil interface of crude oil-water systems generally containing heteroatoms, will have a high molecular weight an a large molecular size. These properties together with the relatively high viscosity of the hydrocarbon phase, are the most important factors for formation of the interface layer as a result of diffusion and adsorption. Thus, depending on the concentration and nature of amphipathic compounds present in the crude oil and on the viscosity of the bulk phase, different times are necessary for the development of interfacial layer and for the attaining of equilibrium state, as shown in Fig. (1). The figure gives the change in interfacial viscosity with time for the crude oil-distilled water systems measured at constant shear rate and 30 oC. Fig. (1) shows that there are difference of orders of magnitude between the interfacial viscosities of the two different crude oils. Hence, the interfacial viscosity is a property of crude oil-water systems that can be in addition to the other prevailing properties of crude oil such as composition, viscosity, density and interfacial tension for the identification of crude oils. Fig. (1) also shows that the formation of the stable interfacial layer is a slow process, needing more than 6 hours. Against this, in the given crude oil-water systems, considerably less time is needed for the attainment of the equilibrium value of interfacial tension, as can be seen on Fig.(2). The contradiction of conclusions drawn from the results of the two properties, is attributed to the fact that the development of a monomolecular layer is sufficient for the attaonment of equilibrium interfacial tension, while longer time is required to develop multilayer to reach the equilibrium of interfacial viscosity.

In Fig. (3) the interfacial viscosities of the two different crude oils-distilled water systems are plotted as a function of shear rate at 30 oC. The interfacial layer for crude oil (B) is bearing toward non-Newtonian flow behaviour, while in the case of crude oil (A) Newtonian flow is characteristic of the interfacial layer. The non-Newtonian character of the interface of oil-water systems can be interpreted by the intermolecular interaction of molecules in the boundary layer. Due to the fact that the structure of interfacial layer does not change at low shear rate, therefore, the interfacial layer is characterized by high viscosity and Newtonian flow behaviour. However, with increasing shear force the interaction gradually diminishes and, consequently, interfacial viscosity decreases with the increase of shear rate. In the range of high rates the interfacial layer is already characterized by low viscosity and also by Newtonian flow, which indicate that the structure causing high viscosity in the layer is completely disintegrated. Hence, the interfacial viscosity of crude oil-water systems cannot be characterized by a single interfacial viscosity but it is strongly dependent on the shear rate.

Ostwald's power low model was found suitable for the empirical description of shear stress-shear rate curves:

$$\gamma = k\tau^{n} \tag{1}$$

The exponent "n" used for the characterization of the deviation from Newtonian flow properties. Fig. (4) shows the yield curves of the system of strongly non-Newtonian character (crude oil B) and the system of Newtonian character (crude oil A) for contact time of one hour. Table (2) contains the values of the constants of Ostwald's relationship. The value of exponent n, for the two crude oils investigated are between n=1, characteristic of

Newtonian flow (crude oil A), and n=1.76, considered as characteristic of non-Newtonian flow (crude oil B). Preceding data presented for the behaviour of crude oil-water interfacial layers belonged to a contact time of one hour. However, it was mentioned earlier that the formation of the interfacial layer is by far not terminated during this time. Curves in Fig. (5) show that, besides interfacial viscosity, the extent of deviation from Newtonian flow characteristics increases also with increasing contact time. It will be noted from data in Table (3) that, in the case of oil B, the value of exponent "n" gradually increases to 3.65 with increasing time.

Effect of salt on interfacial viscosity and interfacial tension were also investigated. Fig. (6) represents the interfacial viscosity as a function of time for crude oil (A)-distilled water and crude oil (A)-formation water systems. It can be seen that on using formation water, the interfacial viscosity is lower by almost an order of magnitude than on using distilled water. Table (4) shows the composition of the formation water in this investigation. Inorganic salts also lower the interfacial tension of oil-water systems as can be seen on Fog. (7). In this figure interfacial tension is plotted as a function of time for crude oil (A)-distilled water and formation water, respectively.

Table (2) Constants of Ostwald's Relationship for the Two Crude Oil-Distillet Water Systems (T = 30 oC, t = 1 hr.)

Crude Oil	K	n
A	2.88	1.05
B	2.45	1.76

Table (3) Change with time of the Constants of Ostwald's Relationship for the Two Crude Oil-Distillet Water Systems (T = 30 oC)

Time, hr	Crude Oil A		Crude Oil B	
	K	n	K	n
0	5.19	1.03	2.46	1.05
1	2.88	1.05	2.45	1.76
2	0.60	1.14	2.40	2.25
4	0.12	1.23	2.23	2.62
6	0.06	1.26	2.11	2.84
24	0.03	1.30	1.70	3.65

Table (4) Composition of the Formation Water.

Components	Concentration, ppm
$CaHCO_3$	888
$CaSO_4$	1937
$CaCl_2$	297
$MgCl_2$	1533
NaCl	8006

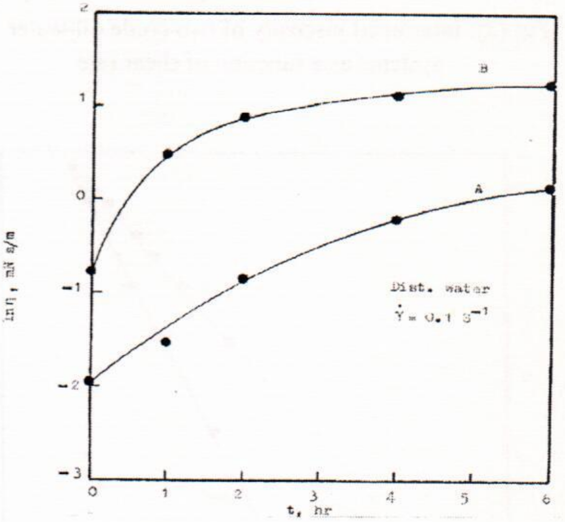

Fig.(1) Interfacial viscosity of two crude oil-water systems as a function of time.

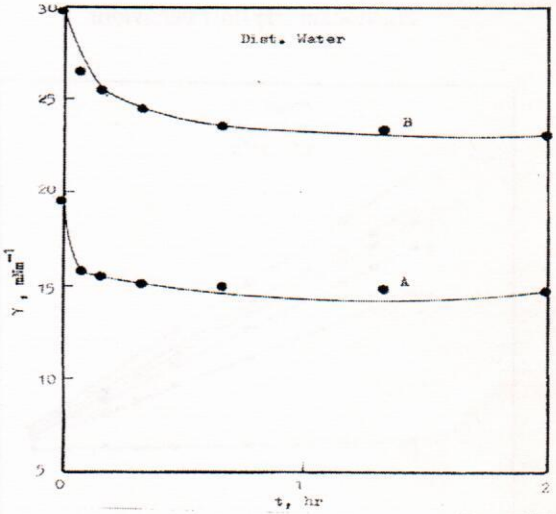

Fig.(2) Interfacial tension of two crude oil-water systems as a function of time.

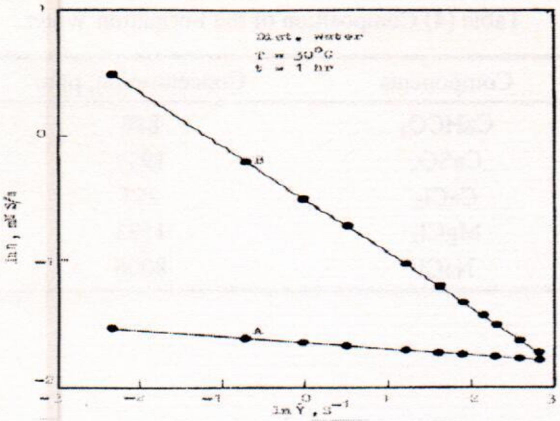

Fig.(3): Interfacial viscosity of two crude oil-water systems as a function of shear rate

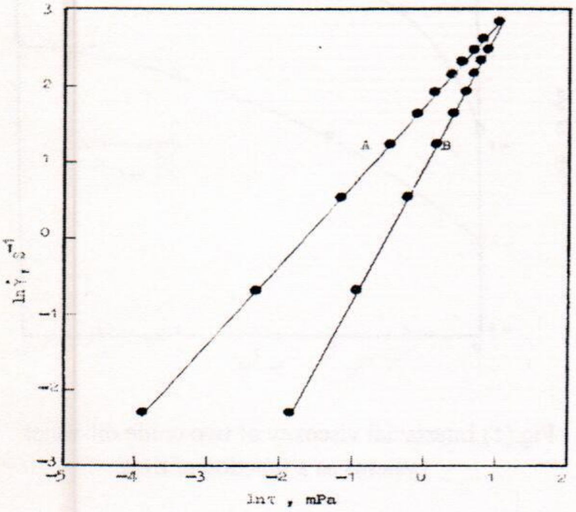

Fig.(4): ln(g) vs. ln(t) relationships obtained for interfacial layers of Newtonian (A) and non-Newtonian (B) flow behaviour

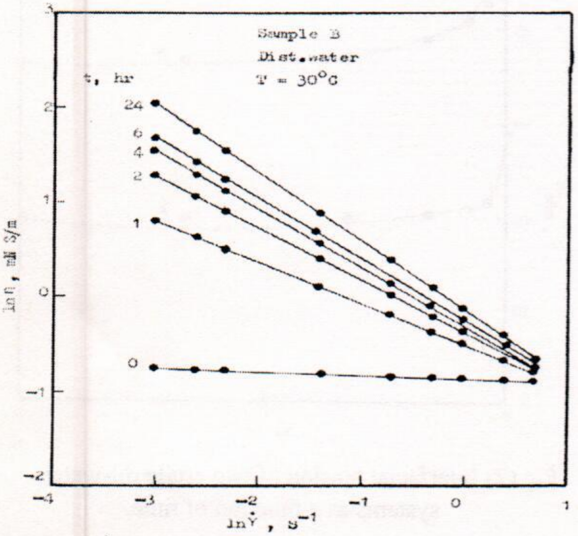

Fig.(5): Dependence of the interfacial viscosity of crude oil-water system upon shear rate and time.

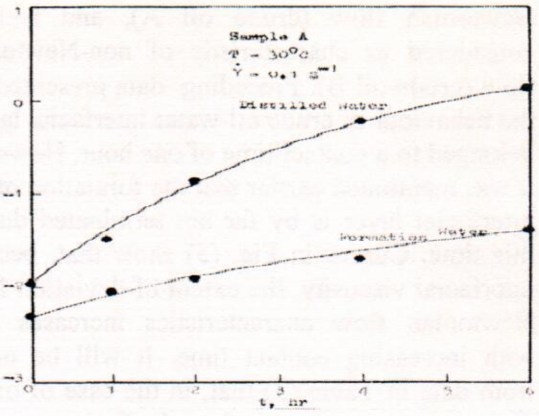

Fig.(6): Interfacial viscosity of crude oil (A) as a function of time, for distilled water and formation water.

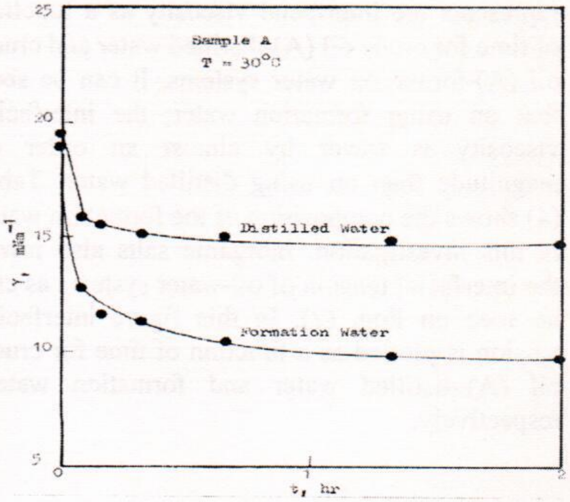

Fig.(7): Interfacial tension of crude oil (A) as a function of time, for distilled water and formation water

CONCLUSIONS

The following conclusions can be drawn from this work:

1. The interfacial viscosities of crude oil-water systems may differ by several orders of magnitude from one another, and may be used for the characterization and identification of crude oils.
2. At the interface of crude-water systems longer time is needed for the attainment of equilibrium of interfacial viscosity than that of interfacial tension.
3. From the rheological aspect, interfacial layers of crude oil-water systems exhibit a non-Newtonian flow behaviour, however, in few

cases a Newtonian flow behaviour was observed.

4. Interfacial viscosity values may be changed by several orders of magnitude with respect to shear rate.
5. The viscosity of interfacial layers and their non-Newtonian flow behaviour increase with contact time.
6. Both the interfacial viscosity and interfacial tension decrease with the presence of salts.

SYMBOLS

K, n	Constants of Ostwald's relationship.
t	Time, hrs.
T	Temperature, °C.
g	Shear rate, sec^{-1}.
h	Interfacial viscosity, mN.sec/m.
G	Interfacial tension, mN/m.
t	Shear stress, mPa.

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