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Interfacial Tension Study in Intelligent Water Flooding

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Abstract: Intelligent water flooding is method to increase oil recovery during previous years. Amount of injected water salt is key factor to intelligent water flooding process. The tension between salty water and oil is important factor to enhance recovery. In fact intra surface tension is effective on capillary number. Decreasing tension between surfaces, capillary number would be increased. The aim of this study is evaluation of water salt effect on surface tension. The interfacial tension between salty water and oil is calculated using salt density, pressure and temperature. The tension is measured using suspended drop method that is dynamic test. Also the effect of time passing on intra facial tension is evaluated. Findings show the lowest tension is defined between 10000-20000 ppm based on salt density. The effect of temperature is more than pressure. Therefore, in high temperature, the tension would be decreased.

Key words: Intelligent water, optimal salinity, interfacial tension, suspended drop, passing time

INTRODUCTION

During million years, the chemical balance was created between crude oil, water, salt and reservoir stone (CBR) that are reservoir oil componenets. Distribution of water and oil is voids have been manifested as oil and water saturation. Due to variability of changes of water and oil components in reservoir and non-homogenous nature of reservoir stones, said distribution may be changed. Based on researchers studies during 20 years about crude oil system wetting properties, various salty waters and stones and water injection, it is found that changes of injected water components would lead to change of balance of CBR system. To create new chemical balance, wetting properties and the tension between water and oil would be changed and oil recovery may be optimized (Sheng, 2013; Ahmed and Meehan, 2011).

Therefore, to increase oil recovery based on flooding, optimal salinity would be required. Therefore water having optimal salinity is named as intelligent water due to increase oil recovery (Torsaeter and Abtahi, 2010). Capillary number is rate of viscous forces to capillary as:

$$N_{ca} = \frac{\mu u}{\sigma}$$

One of the method to increase said number is decrease the tension between oil and water, they would be achieved by optimal salting of injected water (Kumar, 2012).

Intra facial tension is vertical force in direction of length. This is result of molecular reactions in microscopic scale. Fluid mass molecules are absorbed by each others in all directions but molecules at intersection of fluid and other phases would be absorbed to liquid (Aveyard and Saleem, 1967). The direction of this force is defined from intersection to internal part of surface to decrease intersection area (Vijapurapu and Rao, 2004).

In this research , the effects of salinity, temperature, pressure and time is evaluated on tension between water and oil. Optimal salinity is calculated to 1 and 2 cations. By this intelligent water is defined (Hjelmeland and Larrondo, 1986).

The effect of water salinity composition on surface tension: Based on porous environment, current properties would be very important due to properties of the film between water and oil. Researchers evaluated the effect of various types of salts on interfacial tension between salty water and oil. All of them include of positive effect unless potassium (Al-Attar *et al.*, 2013).

Vigaporapor evaluated effect of diluted salty water on dispersion and cohesion behavior of oil on dolomit. They measured interfacial tension using computer method of symmetrical drop form. They found the tension may be decreased with diluting with dionized water, tension had been increased. Dilution of salty water include of significant effect on interfacial tension. Tension decrease had been achieved as 50% based on dilution but it had been increased after that. In this research Total Density of Salty water (TDS) was 9200 ppm (Alotaib *et al.*, 2009).

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Eleter and collegues reported effect of charged ionic compositions on interfacial the tension would be changed. These fluctuations are depended to temperature, pressure and fluid movement in porous environment. These factors are related to interfacial forces to oil recovery. But exact behavior of tension has not been defined based on fluctuations of temperature and pressure.

Hillmeland and Lorande evaluated effect of temperature, pressure and crude oil components on surface properties and found the pressure of surface is effective. The reason of increase of interfacial tension is overall solubility that is depended to change of pressure (Hjelmeland and Larrondo, 1986). Harli and jenings studies effect of temperature and pressure on interfacial tension of benzene-water and normal decan-water. Using suspended drop method; tension is measured based on 25, 125, 170°C and pressure from 0- 900 atm. By this linear relation is defined between said elements (Okasha and Alshiwaish, 2009; Xu, 2005).

By this with increase of temperature and decrease of pressure, interfacial tension would be decreased (Buckley *et al*., 2007). Ogash and elshivayesh evaluated effect of salty water, temperature and pressure on interfacial tension in carbonate reservoir. They measure tension at 25-90°C and pressure of 500, 1000, 2000, 2500 psi to three levels of salts. They found the tension would be increased with increase of temperature firstly, then with fixed pressure, the tension would be decreased (Hassan *et al*., 1953).

Interfacial tension between two non-mixing fluids would be affected by film properties. Therefore, interfacial surface properties are dynamic and function of time. Most of measurements have been performed assuming fluids balance (Jennings, 1967).

Hasan and collegues belived the best time duration to achieve balance is 2 min. Jenings evaluated effect of temperature and pressure on interfacial tension of normal decan-water and benzene-water based on 25-176°C temperature and pressure of 1-817 atm. Balance time duration was assumed as 5 min (Aveyard and Saleem, 1967). Alotidi *et al*. (2009) reported that interfacial tension would be achieved at 800 sec that is depended to temperature and pressure (Amin, 1993).

Backli and fun measured interfacial tension during various times. They used 41 samples of oil and salty water solution. The PH was adjusted based on hydrogen chloride and sodium hydroxide (Abdel-Wali, 1996). Also, chloride sodium was used as salty water. Based on interfacial tension of 21.2 mNm^{-1} time duration duration was drawn as 140 sec (Buckley *et al*., 2007).

MATERIALS AND METHODS

In this research the sample had been provided from IRAN souther reservoirs with API 33.13 all speacification is provided in Table 1. Sodium chloride and calcium chloride are used prepare salty water. These materials had been provided by Germany Merc company. To prepare solutions, distilled water was used. Solutions had been prepared with 30-80°C temperature, 14.7-2000 psia and 2000-120000 ppm (Moeini *et al*., 2014). To measure interfacial tension, suspended drop device was used based on gravity and capillary forces, lowest surface with second phase had been resulted. By this spherical form would be created to drop (Hassan *et al*., 1953).

Based on gravity, drop should be dispersed but due to interfacial tension, spherical form should be maintained. The tension is depended to density between two non-mixing fluids. Therefore below formula would be achieved to measure tension that is basic formula to analyze drop:

$$\sigma = \frac{\Delta\rho g d_e^2}{H}$$

Density measurement: To measure density based on temperature and pressure peaknometer has been used. To measure IFT, density would be used that is very important to analyze drop. After any measurement, the device had been cleaned using distilled water to clean oil phase, acetone was used. Circulating N_2 in glass containers, it was cleaned completely. Having air in water phase would lead to error in measurement. Therefore, to remove it, high temperature should be used in water phase (Niederhauser and Bartell, 1947).

Interfacial tension measurements: To measure interfacial tension between oil and salty water, IFT 400 was used that is made by Fars recovery enhancement company. To measure interfacial tension, suspended drop method was used in this devices. Oil drop would be supplied from higher base with length of 1.91 mm. oil drop was created among water mass. The container was made from stainless

Table 1: Sodium Chloride and calcium chloride densities on 80°C and 14.7 psi

Density of sodium chloride	Concentration
0/9917	2000
0/994	4000
0/999	10,000
1/0059	30,000
1/03951	40,000
1/0423	80,000
1/0623	100,000
1/0764	120,000

steel to resistant against 3000 psia and temperature of 170°C device volume is measured as 50 cm^3. Using photo, the drop had been analyzed to perform this, lab view software had been used with graphical language (Xu, 2005).

RESULTS AND DISCUSSION

Salt and water density measurement: To analyze drop form and to calculate interfacial tension, density of salty water and oil should be determined. To sodium chloride and calcium chloride, densities had been measured at 80°C and 14.7 psi by 2000-120,000 ppm (Okasha *et al*., 2009). All results have been provided in Table 1.

The effect of salinity on interfacial tension: Interfacial had been measured to calcium chloride and sodium chloride with 2000-120,000 ppm at 80°C and 14.7 psi. In fact, salinity is effective factor on interfacial tension.

With increase of salt density, tension would be decreased but until 10,000 ppm. Passing this value, tension would be increased again. Based on results min tension had been observed at 10,000-20,000 ppm. Increasing density, the tension had been increased. Optimal salinity had been defined in this domain, that is shown in Fig. 1. Therefore lowest tension is related to 10,000-20,000 ppm domain. Due to low gravity fluctuations based on 1 and 2 salts, highest capillary number would be expected. Interfacial tension to sodium chloride had been decreased from 18/7565 mNm^{-1} at 2000 ppm to 17/0112 mNm^{-1} at 120,000 ppm. Therefore, increase of oil recovery is expected at optimal salinity and porous environment (Alotaib *et al*., 2009).

Abdelvali observed decrease of interfacial tension to crude oil and salty water at 0-40,000 ppm but would be increased after it (Hjelmeland and Larrondo, 1986). He belived increase of tension at higher densities from 40,000 ppm is result of positive charge of Na^+ and absorption to negative charge among hydrophilic group. Therefore, oleic acid solubility would be decreased in water (Abdel-Wali, 1996).

Interfacial tension fluctuations with salinity is very important factor. Interfacial tension had been decreased due to presence of surfactant of oil ohase and additional density of positive surface but had been increased due to increase of salinity compared to optimal salinity with more increase of salinity, in contact between water and oil, active factors would be prevented and density of surface factors would became negative. During water phase, water molecule entrap salt molcules with hydrogen bonds but due to contact between water and oil, higher energy level would be experienced and bonds would be broken. By this salt molcules would be moved to water phase and

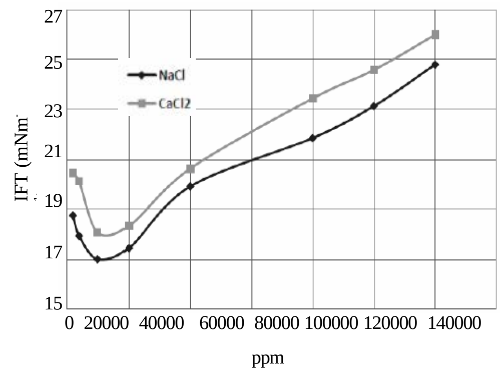

Fig. 1: Fluctuations of interfacial tension based on salinity in 80°C and 14.7 psia

additional density of salt would compensated and due to additional density of negative surface, the tension would be increased >1 optimal salinity (Sheng, 2013; Ahmed and Meehan, 2011; Torsaeter and Abtahi, 2010).

Based on all measurements, interfacial tension of 2 cations had been >1 cations (calcium chloride compared to sodium chloride). To calcium chloride interfacial tension based on optimal density is 18/0762 but to sodium chloride is 17/0122 mNm^{-1} (Kumar, 2012). This shows increase of tension based on cation capacity. This is result of repelling force of surface that lead to increase of interfacial tension (Fig. 1).

The effect of temperature, pressure and time: There are various effective factors on interfacial tension of injected water and oil as temperature, pressure and time duration of contact of two fluids mass and temperature transfer is occurred at surface between oil and water. Interfacial tension is very important to surface properties. With change of temperature and pressure, the tension should be changed. By this fluid movement in porous environment is very important based on interfacial forces to oil recovery (Aveyard and Saleem, 1967).

The effect of temperature on inter facial tension had been evaluated using 10,000 ppm sodium chloride at 80°C and 14.7 psia with increase of temperature tension would be decreased. With increase of tempereature from 30-80°C, the tension would be decreased from 18/9491-17/0221 mNm^{-1} (Fig. 2).

The reason of tension decrease is increase of molecule movement based on temperature. By this system entropy would be increased and free energy would be decreased. Therefore, interfacial tension would be decreased. The other reason is decrease of molecule forces at surface (Gibbs, 1957) (Fig. 3).

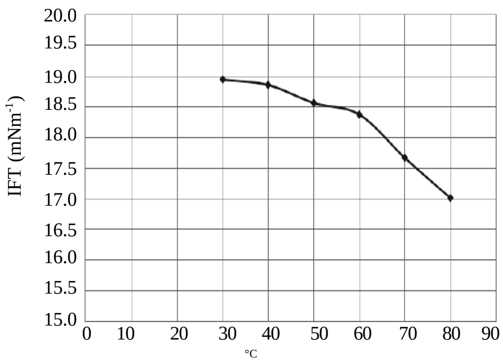

Fig. 2: The effect of temperature on interfacial tension between 10,000 ppm sodium chloride and oil at 14.7 psia

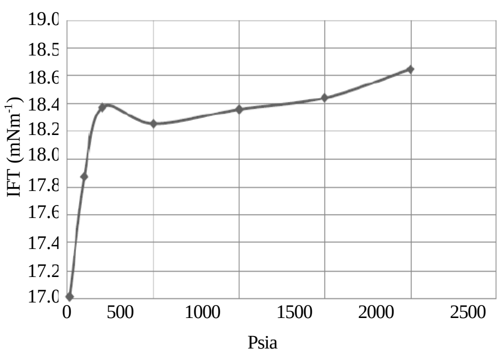

Fig. 3: The effect of changing pressure on interfacial tension in sodium chloride solution with 10,000 ppm and 80°C temperature

CONCLUSION

At optimal salinity, lowest interfacial tension would be occurred with highest capillary value and oil recovery. Intelligent water would be determined proportional to optimal salinity. The effect of 2 cations on interfacial tension is >1 cations. Increasing temperature from 30-80°C, interfacial tension would be decreased as 10%. With increase of pressure, interfacial tension would be increased. The effect of pressure is lower than temperature on interfacial tension. The interfacial tension between salty water and oil would be changed during the time. Passing time, tension decrease would be achieved primarily but after 300 sec, interfacial tension would be decreased with lower, slope and balance would be achieved.

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