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Investigation of effects of salinity, temperature, pressure, and crude oil type on the dynamic interfacial tensions

Mostafa Lashkarbolooki^{a,b,*}, Masoud Riazi^b, Shahab Ayatollahi^c

^a School of Chemical Engineering, Babol University of Technology, Babol, Iran

^b Enhanced Oil Recovery (EOR) Research Centre, School of Chemical and Petroleum Eng., Shiraz University, Shiraz, Iran

^c School of Chemical and Petroleum Engineering, Sharif University of Technology, Tehran, Iran

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ABSTRACT

The main objectives of this study are to determine the influence of crude oil type, salinity, temperature and pressure on the dynamic interfacial tension (DIFT) of crude oil based on the experiments and modeling approaches. DIFT is also modeled using dynamic adsorption models, mono-exponential decay model as well as empirical equations. The results showed that when temperature increases, unlike deionized water which inversion phase temperature was observed, the equilibrium IFT of crude oils/sea water increases due to reduction of surface excess concentration of natural surfactants at the fluid/fluid interface as a dominant mechanism.

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1. Introduction

To meet the high demand of energy, especially from fossil fuels, the academic and industrial petroleum researchers have continually struggled to develop new methods for enhanced oil recovery (EOR) (Abedini et al., 2014; Khulbe et al., 1996). One of such methods that has gained attention in the recent years is smart water and low salinity water flooding (Myint and Firoozabadi, 2015). The popularity of this method is due to its efficiency in water availability and affordability, lower capital and operating costs, ease of injection into oil-bearing formations and displacing light to medium gravity crude oils (Didier et al., 2015). It is well understood that the interfacial tension (IFT) is an important factor in releasing the trapped oil in the pores and throats of porous media (Myint and Firoozabadi, 2015; Didier et al., 2015; Khulbe et al., 1988). Static IFT of aqueous solutions and crude oil and their behaviors as a function of salinity, temperature, pressure and crude oil type have been under study for several decades (Drelich and Miller,

1994; Wang and Gupta, 1995; Xu, 2005; Yang et al., 2005; Kumar, 2012; Moeini et al., 2014; Bayat et al., 2016). It is reported that salts could have a pronounced effect on the IFT of crude oil/water system depending on the type and the amount of surface active material present in the system (Lashkarbolooki et al., 2014a, 2016a). It has been shown that salt can alter the distribution of surface active component at the oil phase/aqueous phase interface (Lashkarbolooki et al., 2014b). It is also reported that salts can accelerate the diffusion of surface active components from the bulk solution to the interface (Bai et al., 2010). However, inspecting the obtained results regarding the effect of salinity on the IFT of aqueous solutions/crude oil systems, shows some contradictory results (Isaacs and Smolek, 1983; Vijapurapu and Rao, 2004; Okasha and Al-Shiwaish, 2009; Bai et al., 2010; Yousef et al., 2011; Lashkarbolooki et al., 2014b, 2016b). For example, IFT studies with formation brines and synthetic reservoir brines that have been performed by Isaacs and Smolek (1983) show that an increase in salinity of the aqueous phase decreases the IFT values. On the other hand,

* Corresponding author at: School of Chemical Engineering, Babol University of Technology, Babol, Iran. Fax: +98 1132334204.

E-mail addresses: m.lashkarbolooki@nit.ac.ir, lashkar.80@yahoo.com (M. Lashkarbolooki).

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Nomenclature

ACO	Acidic crude oil
BCO	Non-acidic (basic) crude oil
C (mol/m ³)	Natural surfactant concentration
D (m ² /s)	Diffusivity
DIFT	Dynamic interfacial tension
EOR	Enhanced oil recovery
GC	Gas chromatography
IFT	Interfacial tension
IR	Infrared
PGW	Persian Gulf water
R (8.314 J/mol K)	The universal gas constant
T (K)	Temperature
TAN	Total acid number
n (dimensionless)	Constants
t (s)	Time
t* (s)	Constant
Γ (mol/m ²)	Surface excess concentration
τ (s)	Adsorption or relaxation time
γ _e (mN/m)	IFT at equilibrium
γ ₀ (mN/m)	IFT at the beginning
γ _t (mN/m)	IFT at time t

Yousef et al. (2011) observed an opposite trend compared to those observed by Isaacs and Smolek (1983). They studied the IFT variation using a crude oil and different brine types including synthetic field connate water, seawater and different diluted seawater types. They observed a general trend of IFT reduction as a result of the salinity reduction (Yousef et al., 2011). Okasha and Al-Shiwaish (2009) studied the effect of formation brine salinity level on the crude oil/water IFT measurements. Synthetic brine solutions were prepared at three different salinities of 52,346, 107,906, and 214,943 ppm. Similar to results of Yousef et al. (2011), IFT values showed decreasing trends as the brine salinity decreased at the same temperature and pressure conditions. It seems that the composition and type of crude oil have a profound effect on the IFT variation of different types of saline waters (Lashkarbolooki et al., 2016b; Lashkarbolooki and Ayatollahi, 2016). To investigate the effects of aqueous solution salinity on the IFT of crude oil/aqueous solution, the impacts of asphaltene and resin extracted from the crude oil were considered by Lashkarbolooki et al. (2014a, 2014b, 2016b). They experimentally showed that asphaltene and resin of crude oil have the dominant effect on the trend of IFT for different salt concentrations.

On the other hand, the literature survey of the impacts of pressure and temperature on IFT indicates different trends. Although the expected and typical trend was to increase IFT with increasing pressure and to decrease with increasing temperature, contrasting trend was reported by many authors (Drelich and Miller, 1994; Wang and Gupta, 1995; Xu, 2005; Yang et al., 2005; Okasha and Al-Shiwaish, 2009; Kumar, 2012; Moeini et al., 2014). For example, Wang and Gupta (1995) measured IFT for distilled mineral-oil and two crude oil types and brine system. The composition of the brine was the same as found in the source reservoirs. The pressure ranged from 200 to 3000 psig, while the temperature varied from room temperature to 94 °C. The IFT for the three systems studied was found to increase with pressure. However, IFT values, either increased or decreased with temperature depending on the system composition. In addition, Okasha and Al-Shiwaish (2009) reported a decreasing trend in IFT for an oil/water system at temperature range from 25 to 90 °C. Increasing the pressure from 500 up to 2500 psig increased the IFT by about 2 mN/m.

It should be noted that, the application of dynamic behavior of IFT due to natural surfactants in the crude oil is more important than that of static behavior (Beverung et al., 1999; Lashkarbolooki et al., 2016c). The studies of dynamic behavior of IFT have been largely ignored in the existing literature due to experimental complexities (Xu, 2005).

Employment of dynamic IFT measurements and dynamic adsorption model by Lashkarbolooki et al. (2016c) could provide an explanation of the contradicting reported trends as a function of temperature and pressure for crude oil/deionized water. We found that the total entropy of the molecules and surface excess concentration of natural surfactant at the interface are the two key parameters, which could affect the IFT through temperature changes. In details, the typical trend is to decrease IFT with temperature due to increasing entropy. However, if the reduction of surface excess concentration of natural surfactant dominates the total entropy of the molecules, then an increase in IFT as a function of temperature would be observed (Lashkarbolooki et al., 2016c).

To follow and complete the previous systematic investigation, this study attempts to draw a relatively complete picture of interfacial properties of crude oil/brine solution by conducting fundamental experiments and modeling approach to determine the influence of natural surfactant and oil composition on the oil–brine dynamic IFT as functions of pressure and temperature. In other words, similar approach of our previous study is applied to investigate the effect of salinity on the dynamic IFT (DIFT). In this way, dynamic IFT of two different types of crude oil (named ACO and BCO) in Persian Gulf water (PGW) were measured under different operational pressures (i.e., 500, 1000, 2000 and 4000 psi) and three constant temperatures of 30 °C, 50 °C and 80 °C. Moreover, the obtained experimental and modeling results of crude oil/PGW systems are compared to the recently published results (Lashkarbolooki et al., 2016c) between dynamic IFT of crude oil/water.

2. Model of dynamic interfacial tension

The polar components of crude oil including asphaltene and resin are two main effective factors of the behavior of the dynamic IFT as a function of temperature and salinity (Malmazet et al., 2015). Generally, there are two general perceptions to describe the dynamics of adsorption of asphaltene and resin at liquid interfaces (Xu, 2005; Dukhin et al., 1995; Diamant and Andelman, 1996; He et al., 2002). The diffusion controlled model, which is known as the rate-controlling process, assumes the diffusional transport of interfacially active molecules from the bulk to the interface, while the so-called kinetic controlled model is based on transfer mechanisms of molecules from the solution to the adsorbed state. In other words, the attachment of the molecules onto the interface is due to high adsorption activation energy barriers (Xu, 2005). Normally, the kinetics part of the process is much smaller than the diffusive part; therefore, the adsorption of common non-ionic surfactants is expected to be controlled by the diffusion coefficient (Ward and Tordai, 1946; Miller, 1980; Diamant et al., 2001).

Lashkarbolooki et al. (2016c) used short and long times diffusion-limited approximations, mono exponential decay model and empirical equation to model of the DIFT data of crude oil/water. The used models with description of the obtained properties are listed in Table 1 and the models symbols defined in the nomenclature section. More information about the modeling of DIFT can be found in the preceding paper (Lashkarbolooki et al., 2016c). The models listed in Table 1 are applied to the measured DIFT of crude oils/PGW and through that adsorption, equilibrium and meso equilibrium times, the diffusivity of natural surfactants from the bulk of crude oil toward the aqueous solution interface, and surface excess concentration of natural surfactants at the crude oil/PGW interface are obtained. The obtained results are then compared with the results of the previous study.

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