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EXPERIMENTAL MEASUREMENTS AND MODELING OF INTERFACIAL TENSION FOR INJECTED GAS + LIVE OIL SYSTEMS AT ELEVATED PRESSURES

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Abstract

Interfacial tension is a physical parameter which plays an important role in many processes in a number of industrial applications. In the petroleum industry, near-critical fluids recovery, gas condensate recovery, in particular by gas injection, wetting behavior, secondary and tertiary crude oil recovery, low surface tensions are very important to measure. These surface tensions (i.e. liquid/ vapor interfacial tensions) must be accurately known because of their dominating influence on capillary pressures, relative permeabilities and residual liquid saturations. These properties depend heavily on the density of the phases involved.

One objective of this study was to develop an accurate measuring procedure for this system using the pendant drop method based on Iranian oil reservoir samples and its immiscible injecting gas at reservoir condition. Another objective was to study the behavior of the interfacial tension with pressure and temperature in a range of (101.35-31026.41 kPa) and (43.3-93.3ºC). Since experimental measurements are often unavailable, expensive and time-consuming, models are regularly used. A new correlation for estimating of IFT was provided using non-linear multivariable regression method. This correlation uses density difference as input value, detailed comparisons show that validity and accuracy of the new correlation is in good agreement with experimental data set of Iranian oil reservoir fluids.

Keyword: interfacial tension; pendant drop; correlation, gas injection; temperature; pressure.

1. Introduction

Interfacial tension (IFT) is a measurement of the cohesive (excess) energy present at an interface arising from the imbalance of forces between molecules at an interface (gas/liquid, liquid/liquid, gas/solid, and liquid/solid). When two different phases (gas/liquid, liquid/liquid, gas/solid or liquid/solid) are in contact with each other the molecules at the interface experience an imbalance of forces. This will lead to an accumulation of free energy at the interface. If the surface investigated is the interface of two immiscible liquids the measurement is normally referred to as interfacial tension. There are many approaches for computing the liquid–vapour surface tension of simple fluids or mixtures [1-2].

Accurate and reliable information on interfacial tension (IFT) is of major importance in both petroleum and reservoir engineering. This importance is sensed when dealing with IOR and EOR process where the relative magnitude capillary, gravitational and viscous forces affect the recovery of hydrocarbon [3]. The capillary pressure is the concept which is often used in reservoir studies to consider the effect of surface forces on the fluid distribution within a reservoir. The capillary pressure is related to the interfacial tension and the pore characteristics [4]. Therefore measuring precise IFT in process such as immiscible gas injection leads to find a reliable estimation from capillary trapping forces at reservoir condition [5]. It has been established also by the several researcher that the relative permeability, which describes the multiphase flow behavior in the reservoir rock, may strongly depend on the interfacial tension [6].

The interfacial tension increases with decreasing pressure [7]. An equation describing the reported data is also shown. The interfacial tension is very small for near critical mixtures and approaches zero as the critical point is approached. Hence the effect of temperature on IFT depends on the relative position to the critical point. For a gas condensate, IFT is expected to decrease by decreasing temperature, where the opposite is expected for an oil sample. The interfacial tension showed a pronounced dependence on pressure and temperature [8-9].

In this work the pendant drop method is used to develop an accurate measuring procedure for Iranian oil reservoir samples and its immiscible injecting gas at reservoir condition. Another objective was to study the behavior of the interfacial tension with pressure and temperature. A new correlation for estimating of IFT was provided using non-linear multi-variable regression method. This correlation uses density difference as input value; also accuracy of the new correlation is in good agreement with experimental data set.

2. Measurement method

The gas-liquid interfacial tension at high pressures is commonly measured by a pendant-drop apparatus. The apparatus allows for the determination at reservoir conditions of surface tension (liquid-gas) and interfacial tension (liquid- liquid). In this technique, a liquid droplet is allowed to hang from the tip of a capillary tube in a high pressure visual cell filled with its equilibrated vapor, as shown schematically in Fig. 1. Drop formation is performed under controlled with a calibrated and accurate video lens system; the complete shape of the drop is analyzed with advanced drop shape analysis software. Using the drop dimensions on the photographic image, and known needle dimensions, the interfacial tension for a selected fluid can be determined [10]. When compressible fluids are present, dynamic phenomena play an important role, especially in the high-pressure area, and the interfacial tension can change drastically during the life of a pending drop, making it necessary to find a reliable experimental procedure and in right time of pending drop's life snapshot must be taken.

Fig. 1 Pendant-drop apparatus.

The shape of liquid droplet at static conditions, controlled by the balance of gravity and surface forces, is determined and related to the gas-liquid interfacial [11] by:

$$\sigma = \frac{g {d_e}^2}{l}(\rho^l - \rho^v) \qquad (1)$$

where, g is the acceleration due to gravity and ρ^l and ρ^v are the liquid and vapor phase (mass) densities, respectively, l, the drop shape factor, is a function of R= d_s/d_e, where d_e is the equatorial diameter, or the maximum horizontal diameter of the drop and d_s is the diameter of the drop measured at the height d_e above the bottom of the drop, as shown in Fig. 2. Tabulated values of l, determined by relating the pressure difference across the interface to the interface curvature, vs. R, reported by several investigators [12].

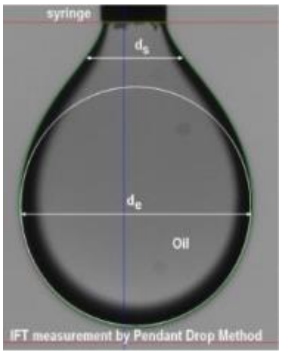

Fig. 2 IFT measurement by pendant drop method.

3. Experimental procedure

The experimental procedure using IFT 700 apparatus for measuring interfacial tension parameter are described in this section. First of all Sample was pressurized until 5000 Pisa to become monophonic. For asphaltenic oil samples since asphaltene fractions include soluble and insoluble colloid particles, it is recommended that samples remain at reservoir temperature and aged for a sufficient period of time. Above the saturation pressure sample was injected through the capillary needle in specified pressure and temperature. At pressures below the bubble point pressure associated gas was evolved and in this steps two phases was appeared. Consequently at each step liberated gas removed from live oil and remained high pressure oil was used to inject through pendant drop instrument. Visual chamber was vacuumed and was heated up to reservoir temperature, temperature could be regulated on liquid and gas phases using temperature regulator of the instrument. Temperature effects on density differences. Gas sample cylinder warm up using electrical jacket and injected as bulk phase. At this step oil and gas cylinders was filled at reservoir temperature at monophonic condition and every thing was ready to open the micro valve and create a well-formed droplet through pendent drop needle. Since mentioned before droplet growing process was monitored with accurate video lens system and at right time a snapshot was taken from stabilized droplet at reservoir condition. Droplet picture was analysed with image processor software and droplet angle at both side was measured and converted to interfacial tension value at reservoir pressure and reservoir temperature Fig. 3.

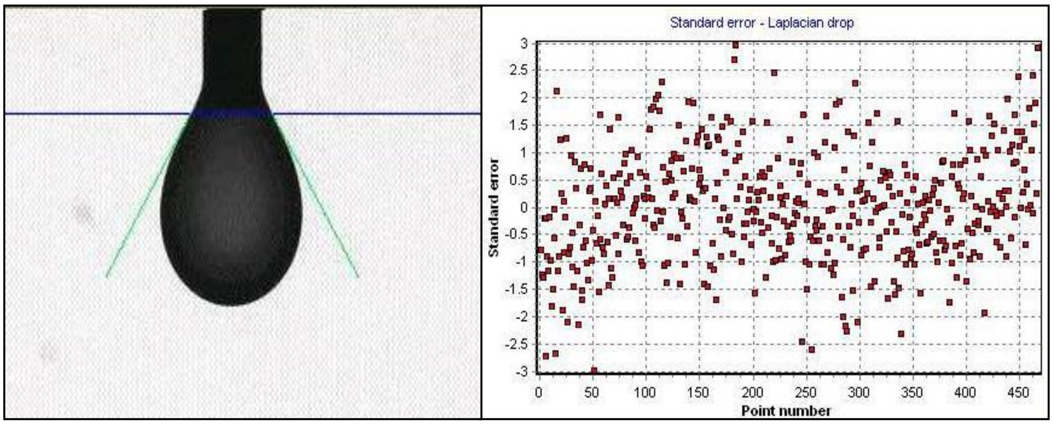

Fig.3 Liquid Drop Snapshot Analysis.

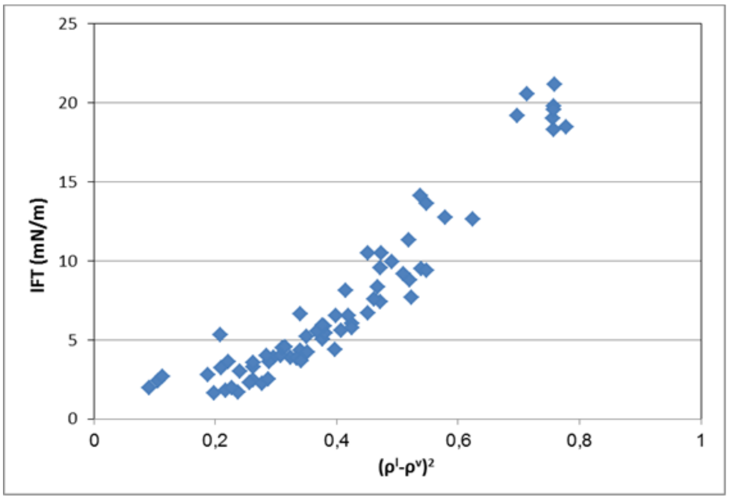

Fig. 4 Experimental data from pendent drop method.

4. Regression function

A regression curve was calculated on the basis of the experimental data determined in this work. It allows the data within the experimental range to be interpolated with accuracy greater than 95%. Eq. (2) describes our non-linear regression model:

$$\sigma = A + B * dd * \ln dd + C * \exp^{-dd} \quad (2)$$

$$dd = (\rho^l - \rho^v)^2 \quad (3)$$

A = -45.5563; B = 37.7810; C = -37. 9546

where dd represents the squared density difference of oil and gas components at specify temperature and pressure. The unit of dd is g^2cm^{-6}.

Levenberg-Marquardt method was employed for the regression. The quality of the regression is shown in residual error graph of Fig. 5, where the residual error of the regression value from each experimental data point is plotted against the squared density difference.

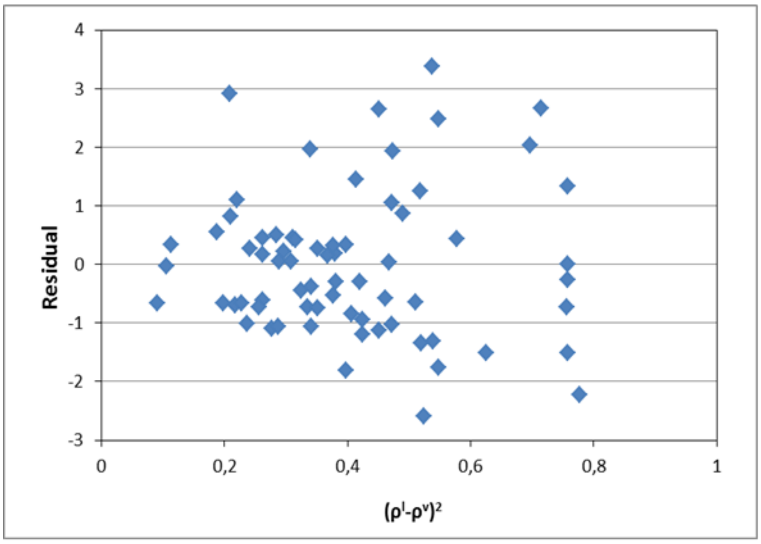

Fig.5 Residual error of the regression value from each experimental data point.

Due to the regression procedure, difference between the actual data points and the curve generated from the predicted values, residual values are almost in between ±3. Generally 88% of residual values are less than ±2. Regarding to the error values at low density difference there is lower differences between the experimental data and the curve generated from the fitted model.

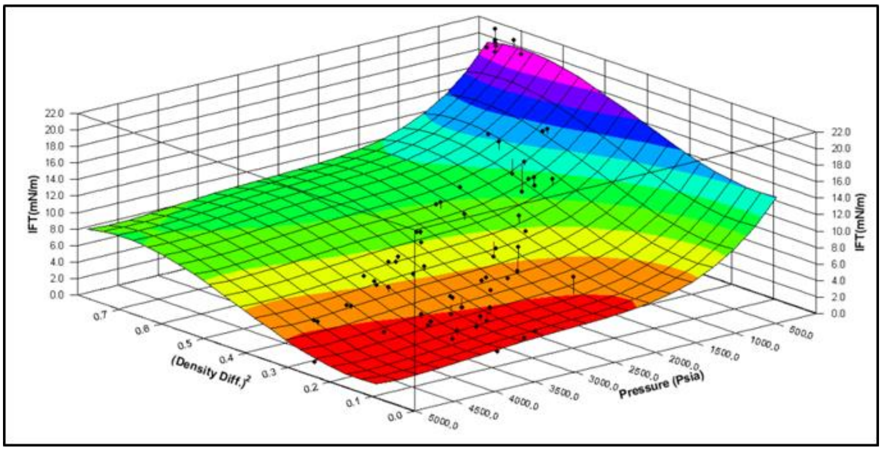

Fig. 6 Interfacial tension derived from regression function.

In Fig. 6, we have plotted the interfacial tension derived from our regression function as a function of pressure and density difference. According to regression result, R^2 or coefficient of multiple determinations has value of 0.975 and it shows a good fit of data points. As illustrated in figure 5 there is increasing trend for interfacial tension by increasing density difference. This trend is more obvious at low pressures in contrast with high pressures. In addition interfacial tension decreases when increase pressure according to experimental data which obtained by pendent drop method.

5. Conclusions

Accurate and reliable information on interfacial tension (IFT) is of major importance in both petroleum and reservoir engineering. In this study an accurate experimental measuring procedure was developed using the pendant drop method based on Iranian oil reservoir samples and its immiscible injecting gas at reservoir condition. In this work behavior of the interfacial tension was studied with pressure and temperature. Since experimental measurements are often unavailable, expensive and time-consuming, models are regularly used. A new correlation for estimating of IFT was provided using non-linear multivariable regression method. This correlation uses density difference as input value, detailed comparisons show that validity and accuracy of the new correlation are in good agreement with experimental data set of Iranian oil reservoir fluids. In addition, interfacial tension derived from our regression function as a function of pressure and density difference.

This function is useful for interpolating the interfacial tension of the associated gas + live oil system. The accuracy of the regression function can be further improved if more experimental data obtained and added to the model.

Nomenclature

T	*Temperature*
P	*Pressure*
ρ_q	*Gas Density*
ρ_o	*Oil Density*
σ	*Gas-Oil Interfacial Tension (mN/m)*
d_e	*Equatorial diameter*
d_s	*Diameter of the drop measured at the height d_e above the bottom of the drop*

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