Evaluation of Interfacial Tension by Image Processing of the Shape Drops

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Abstract

An interface of fluid phases is created by unbalanced molecular attracting and repulsive force. Evaluating the gas-liquid interfacial tension is very important and major interest in injection processes. The interfacial tension between gas and liquid phases can be measured by different methods in the reservoir and surface condition. VIT (vanishing interfacial tension technique) is a laboratory method that calculates interfacial tension for mixture of oil-gas in the series of pressure. Estimating the amount of the minimum miscibility pressure (MMP) is taken to be the pressure at which the interfacial tension tends to zero when plotted against pressure. The surface tension calculation is done by image processing of sessile and pendant drops of crude oil enclosed in a surrounding medium of the injection gas. In this paper use a computer program for processing and digestion the shape of a pendant drop has been brought.

Keywords

Interfacial Tension, Drop Shape Analysis, Minimum Miscibility Pressure, Vanishing Interfacial Tension Technique

Subject Areas: **Chemical Engineering & Technology, Computer Engineering, Industrial Engineering, Software Engineering**

1. Introduction

All definitions of miscibility require the absence of an interfacial tension between the injected gas and the crude oil at reservoir conditions, at miscibility point [1]-[3]. This means that the interfacial tension between two immiscible fluids must continuously be reduced as they approach miscibility and the interfacial tension becomes zero at miscibility point [4]. In the VIT method, the miscibility conditions of pressure and composition are de-

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termined as those at which the interfacial tension is zero [5]-[8]. However, it is impossible to measure interfacial tension when it becomes zero [9] [10]. So the VIT method relies on measuring gas-oil interfacial tension to as low value as experimental accuracy allows, and then extrapolation of data to zero interfacial tension (IFT condition). Thus the VIT method requires accurate measurement of gas-oil interfacial tension at reservoir conditions, which is discussed below [3].

2. Interfacial Tension

If we want to store the energy, we should create surfaces. The work required to distort a liquid to increase its surface area by an amount of *dA* is proportional to the number of molecules that must be brought up to the surface so:

$$\delta W = \gamma \cdot dA$$

where γ is the interfacial tension [11]. In the other word:

(γ) is the energy that must be supplied to increase the surface area by one unit. Surface tension can also be defined as a force per length unit. Surface forces affect fluid phase equilibrium [11]. A tension always exists at the interface of fluid phases due to unbalanced molecular attractive and repulsive forces. Surface and interfacial tension of fluids are results of molecular properties occurring at the surface or interface. Surface tension may be defined as the contractile tendency of a liquid surface that exposed to the gases [12]. The interfacial tension is a similar tendency which exists when two immiscible liquids are in contact.

3. Measurement of Interfacial Tension

Numerous methods and techniques exist for measuring interfacial tension. Some of these standard methods and techniques are:

1) Wilhelmy's method, in which first dips a thin plate or a ring and then measures the capillary force acting on the plate.

2) The rise of a liquid in a small capillary tube.

3) The methods based on the shape of a drop, in which one characterizes the shape of drops in various configurations (deposited, rotating, hanging).

4) Capillary waves: one excites capillary waves and one measures the relation between frequency and wavelength by monitoring the distortion of the surface by means of a laser beam [11].

4. Methods Based on the Shape of Static Drops

Small drops tend to be like a globular because surface forces depend on the area, which decreases as the square of the linear dimension, whereas distortion due to gravitational effects depends on the volume, which decreases as the cube of the linear dimension. Likewise, a drop of liquid in a second liquid of equal density will be spherical. However, when gravitational force and surface tension effects are comparable, then one can determine in principle the surface tension from measurement of the shape of the drop [11].

The general procedure is forming a drop under condition such that it is not subject to disturbances and then measuring its dimensions or profile from a photograph or with digital image processing of video images. Recently the image analysis has been automated to improve accuracy over manual analysis. In an axisymmetric drop shape analysis of surface tension, the pendant drop geometry is preferable because large drops can be made axisymmetric easily. Sessile drop however, are useful for study of the contact angle. The greatest accuracy is achieved with fewer and very accurate points on the drop surface rather than a large number of less reliable points [13].

4.1. Pendant Drop Method

The gas-liquid interfacial tension is commonly measured by pendant drop apparatus at high pressures. In this method, a liquid droplet is allowed to hang from the head of a capillary tube at high pressure, visual cell filled with its balance vapor. When the liquid droplet is at the static situation, its shape is adjusted by the balance between gravity and surface forces [11]. The shape of the droplet relates to gas-liquid interfacial tension by this equation below:

$$\sigma = \frac{gd_e^2}{l}\left(\rho^l - \rho^v\right)$$

where, g is the acceleration due to gravity and ρ^l and ρ^v are the liquid and the vapor phase 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.

4.2. Sessile Drop Method

Determining the liquid surface tension from observations made on a large (sessile) drop resting on a horizontal surface has the advantage that readings are taken only on the liquid surface and do not involve angles of liquid and solid contact When we want to use this method.

h measurement ,the vertical distance between the top of the drop and the horizontal plane of maximum section and the amount of the diameter ($2r$) which we insert it into the correction factor to be used in the well-known formula for a droplet with infinite diameter:

$$\gamma = \frac{1}{2}\rho g h^2$$

4.3. Spinning Drop Method

In this method a drop of fluid with low density is being injected into a container of the denser liquid and the whole system is rotated. As a result, in the centrifugal area, the drop lengthens along the axis of rotation and because this action increase the area and interfacial tension is against the increasing the area [11]. So interfacial tension is against the elongation and a configuration which minimizes the system free energy is reached. The method is similar to that, for the pendant drop, the gravitational acceleration g replaced by the appropriate acceleration term made from a centrifugal field [13].

If the fluid densities are ρ_A and ρ_B, and the angular velocity ω of rotation is known, then interfacial tension can be calculated from the measured drop profile. When drop length is much greater than the radius r_m, the following approximate expression holds:

$$\sigma = \frac{\left(\rho_B - \rho_A\right)\omega^2 r_m^3}{4}$$

The spinning drop device has been widely used in recent years to measure very low interfacial tensions. Unlike the other methods, no contact between the fluid interface and a solid surface is required [14].

5. Vanishing Interfacial Tension

For the exact measurement of IFT between oil and gas it needs to density be measured in experiment's pressure and temperature. For measurement of density in different pressure and temperature DMA HPM (Anton-Paar, Austria) densitometer is used. For the regulating of densitometer's temperature, it connected to an oil (ghee) bath (haber) and then it regulated. (By using detent around DMA HPM, temperature regulating will be done quickly) [15]. After density determination, is the turn to IFT between oil and gas be measured. In **Figure 1** IFT measurement is showed. Which includes one observable cell (case or chest) with high pressure. A high pressure emerald glass is in front of the cell. High pressure cell includes a capillary tube which is on the top of it that we inject the oil droplets to gas by this from above. This system includes a device for oil injection [15] [16].

A high pressure pomp and a pressure gauge for pressure measurement is in the system. All the system is in the heat cell that can be controlled. This picture tacked by a camera, there is a light source on the other side of the cell which provide the mentioned light. Camera is connected to a computer monitor equipped with a software named droplet's shape analysis which is used for IFT calculation between oil and gas. A desire gas mixture injected to the observable high pressure cell that has the reservoir temperature, injection continues up to the selected pressure [15] [16].

For the IFT measurement it is important and effective that the different part of the machine be cleaned, so at first the different parts which of fluid existence in them be cleaned by toluene, aceton and water. Then we

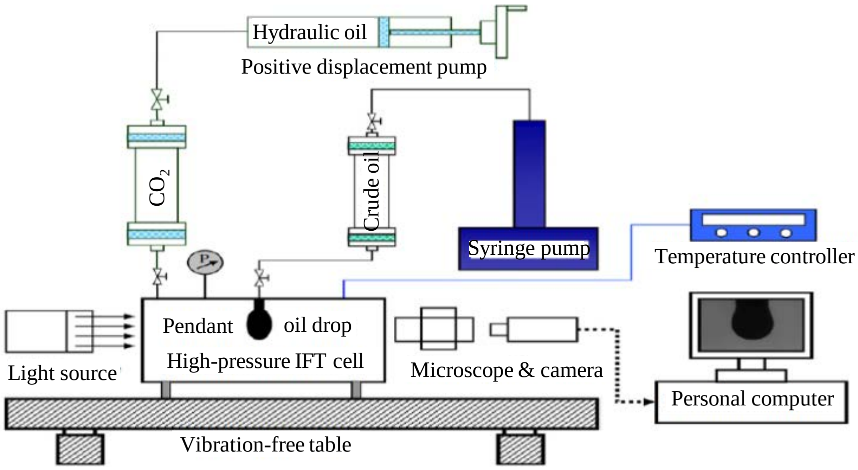

Figure 1. Schematic illustration of the experimental setup.

regulate the temperature of observable cell, total fluid storage tank and droplet. By fluid injection piston, considered oil entered the droplet fluid injection cell and also considered gas entered to droplet fluid injection tank. Pressure producer is used for injecting gas to observable cell and considered gas injected to cell at desire pressure. Then it has enough time to reach complete equilibrium (pressure and temperature of observable cell to be constant). The oil fluid which temperature achieved balance in tank, injected from above of cell as droplet with opening the valve slowly. Droplet shap analysis software calibrated by fluid injecting tube diameter and oil and gas densities in considered pressure entered. IFT measurement continued up to it gets constant (reaching thermodynamic equilibrium). To achieve thermodynamic equilbrium quickly, several oil droplets (10 - 20 droplets) injected to cell. In this experiment time equilibrium is considered that IFT not to be changed during time. According to plant's few mili newtonian oscillation, IFT changes v.s time traced at first then average of measured IFT in the last 100 second districted as IFT in that pressure and temperature.

6. Experimental Works

Input parameters program requires to analyze the image and measure interfacial tension are gas density, liquid (crude oil) density, needle size (to use as scale) and the address of the image.

In this method pendent drop equation is used for measuring the interfacial tension. (Most of available software's use this equation to evaluate the interfacial tension) [17].

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

Values of gas and oil densities are measured experimentally with Anton Paar density meter (A useful system for measuring densities of the fluid in high temperature and pressure condition with high accuracy).

The main part of this program according to the pendent drop equation is calculating the biggest horizontal diameter of the liquid drop named d_e in above equation. The small liquid drop is allowed to hang from the tip of a capillary tube in a high pressure visual cell filled with its equilibrated vapor.

d_e is the diameter of the drop measured in the altitude of d_e above the bottom of the drop and is another important required parameter for input of program. It is also calculated by processing the image of the drop after recognizing d_e with this program. Finally the last required parameter is drop shape factor, determined by fraction of d_s/d_e from the table of drop shape factor [18].

There are different methods for processing the image of drop. These methods are using the edge correlation of the drop or checking pixel by pixel.

In this work because the processing is done under the static condition for decreasing the error of measurement the method of checking pixel by pixel is used.

The purpose of producing this program is to correct the limitation and existence problems and omit them.

Some of these restrictions and problems are:

1) Most of these softwares are monopoly so the processing of images of other systems and cameras, even the images of the same other system, cannot be done.

2) It is not feasible in some software to process the own system images, because their measured values are lost or not available for a second time.

3) Softwares are designed according to the camera of the system and the image resolution of that camera, and it is impossible that software had enough accuracy for processing images from different cameras because of different resolutions.

So one of the important corrected of the problem in this program is to create a method for processing images from different camera with different resolutions.

7. Results and Discussion

Interfacial tension between an oil sample with 28 degree of API and known composition has been measured. Values of interfacial tension measured by Vinci VIT apparatus and the recorded image was analyzed by our program that explained above. These values are compared with Vinci's results and reported in **Table 1**. The fourth column of the table indicates the percent deviation from the results of Vinci's VIT apparatus.

Figure 2 Shows oil drop shape in high pressure visual IFT cell filled with CO_2 in sequence pressure and 50˚C.

Figure 3 shows IFT measured with Vinci VIT apparatus against pressure. Value of minimum miscibility pressure of the oil sample and CO_2 evaluate 1502.99 if interfacial tension extrapolates to zero when plotted against pressure.

Figure 4 shows IFT measured with IFT program image against pressure.

Value of minimum miscibility pressure of the oil sample and CO_2 evaluate 1502.99 if interfacial tension extrapolates to zero when plotted against pressure.

Table 1. Comparison between IFT measured by Vinci's VIT apparatus and our program in sequence pressure.

Pressure (psi)	Vinci's results (mN/m)	Designed program results (mN/m)	Deviation from Vinci's results (%)
700	13	12.83	**−1.3**
800	11.62	11.55	**−0.6**
900	9.88	9.77	**−1.01**
1000	8.33	8.26	**−0.84**
1100	6.42	6.44	**+0.31**
1200	4.92	4.99	**+1.42**

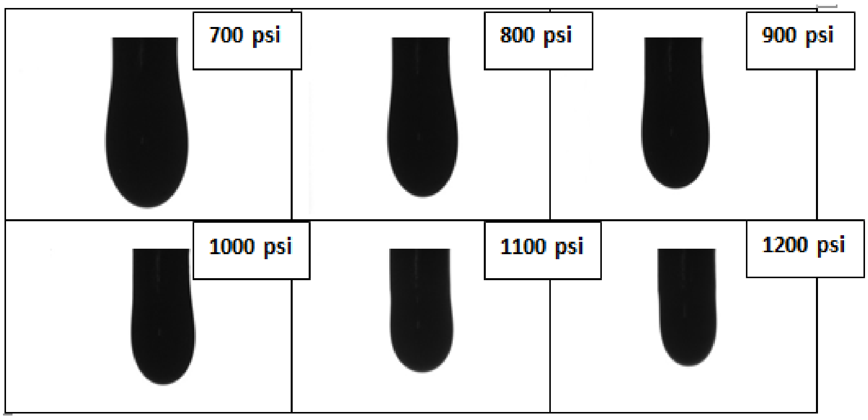

Figure 2. Shape of oil drop in high pressure visual cell filled with CO_2 in different pressure.

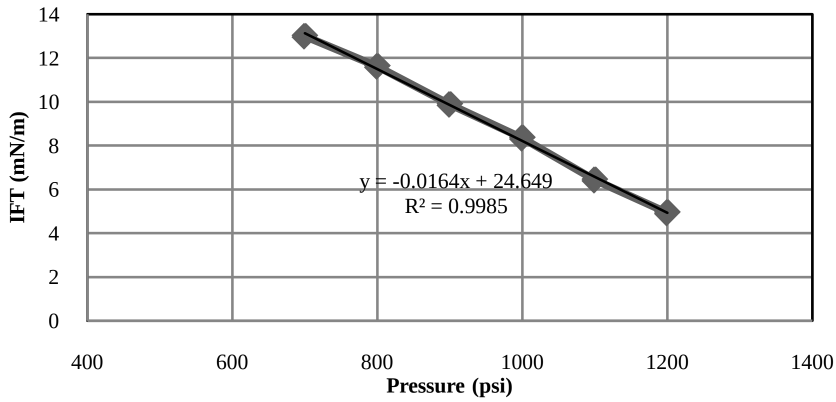

Figure 3. Vinci's interfacial tension results against pressure.

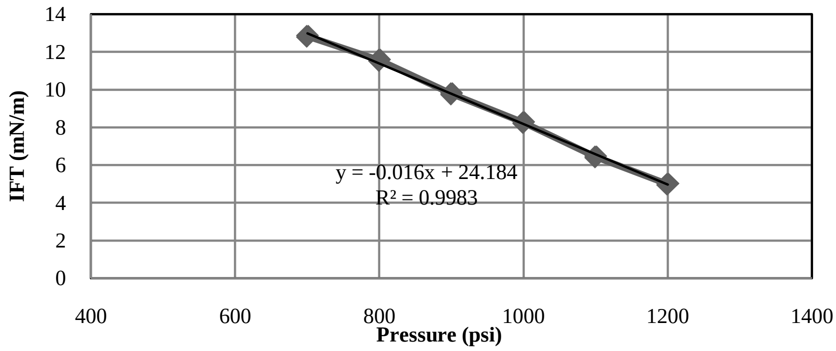

Figure 4. IFT program image processing interfacial tension result against pressure.

8. Conclusion

According to the results, IFT program image processing has measured the values of interfacial tension with an acceptable accuracy nearby the values measured with Vinci VIT apparatus. In other words, the deviation between program results and Vinci VIT apparatus is rarely more than one percent. The value of minimum miscibility pressure of this program has a deviation less than 9 Psi from VIT system results for this specific oil sample. This is the deviation which is less than 0.6 percent.

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