EFFECT OF TEMPERATURE AND PRESSURE ON CONTACT ANGLE OF QUARTZ-WATER-BITUMEN SYSTEM

Maryam Rajayi, Apostolos Kantzas
University of Calgary, Canada

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ABSTRACT

One of the novel technologies to produce bitumen from oil sands is the injection of steam into the reservoir. The injected steam contacts the oil sand, heats, mobilizes and pushes the bitumen out of the reservoir. The stability of the water–bitumen interface is a crucial factor in the steam injection method. The shape, strength and energy of this interface are expected to play important roles in the recovery of bitumen from oil sands. However, measurements on bitumen-water interfaces are not apparent in the literature. A measurement of relevance would be the contact angle of water and bitumen at different temperatures. In this paper, the results of contact angle measurements of water and bitumen are presented. The measurements cover a temperature range from ambient to the saturation temperature for a given pressure. The experiments are run in X-ray transparent cells and the contact angles are measured through images taken in a micro-CT scanner.

INTRODUCTION

Thermal recovery of bitumen causes many changes in the reservoir and in fluids properties such as viscosity, density of each fluid, interfacial tension and wettability of the aqueous-hydrocarbon and rock-fluid interfaces.

Anderson (1986a) defines wettability as “the tendency of one fluid to spread on or adhere to a solid surface in the presence of the other immiscible fluids”. The wettability values and its variations in thermal recovery operations have an important role on reservoir characterization and oil recovery.

In this paper, we briefly introduce methods of measuring oil sand reservoir wettability and investigate the wettability of oil sand reservoirs at elevated pressure and temperature using the contact angle measurement method. The contact angles of bitumen-water systems on a quartz surface are measured using a micro computerized tomography (CT) scanner.

REVIEW OF THE LITERATURE

Methods of Wettability Measurement

Wettability measurement in the oil recovery industry is quite popular and several different methods have been used to characterize the wettability of different reservoirs.

These methods are reviewed in detail by Anderson (1986b). They are generally categorized in two major groups; qualitative and quantitative methods.

Common qualitative methods for wettability measurement are imbibition rates, microscope examination floatation, glass slide method, relative permeability curves, permeability-saturation relationships, capillary pressure curves, displacement capillary pressure, reservoir logs, nuclear magnetic resonance (NMR) and dye adsorption. Quantitative methods include contact angle, spontaneous and forced imbibition (Amott) and USBM wettability method. According to Anderson (1986b) the contact angle method is used to measure the wettability of a certain surface, but the Amott and USBM methods are used for core wettability measurements. Quantitative methods are more commonly used; nevertheless, there is no single universally accepted method.

Contact Angle

Contact angle (θ) is the angle at which a fluid-fluid interface meets the solid surface. The (θ) is always measured relative to the denser phase. In this work, water is the dense phase. The contact angle method is very useful for wettability measurement when working with clean surfaces and pure fluids. Typically contact angle measurements are done on oil-water-quartz surface systems in order to study the wettability variations under different temperatures, pressures and salinities.

For (θ) measurement two immiscible fluids are placed on a solid surface; fluid 1 is the denser fluid. The (θ) can vary between 0^o and 180^o. If (θ) is less than 75^o, fluid 1 is the wetting phase and if (θ) is more than 105^o fluid 2 is the wetting phase. The (θ) between 75^o and 105^o define what is known as neutral wettability and indicate that the surface does not have any preference to contact more with any of the fluids.

Methods of Contact Angle Measurement

Several methods have been used to measure the contact angle such as: capillary rise, tensiometric, cylinder, vertical rod, captive bubble, Wilhelmy plate, tilting plate, pendant drop, sessile drop as described by Adamson (1997), single-crystal sessile drop, dual-drop-dual-crystal (DDDC). Details can be found in the works of Rao (1996); Rao and Girard (1996); Rao (1999); Vijapurapu et al. (2002); Vijapurapu and Rao (2004).

The contact angle values in the aforementioned methods are measured either by looking directly at the sample interfaces or by looking at a photograph of the contact area. Therefore, in the experiments the transparent phase (water or gas) should always play the bulk fluid role and oil is the drop phase. Therefore, with these techniques, it is impossible to study the contact angle of a drop of water or a bubble of gas inside the oil phase. In this study, the use of a micro-CT scanner made it possible to see through the oil as the bulk fluid and investigate the contact angle of the water as a sessile drop on a quartz plate. The images taken by the micro-CT can detect the drop of water inside the bitumen (oil) phase.

EXPERIMENTAL PROCEDURE AND SETUP

The micro-CT scanner used for imaging the contact angle is a SKYSCAN 1072. In order to measure the contact angle a micro model containing the quartz crystal was designed and constructed. The micro model is an aluminum cell and its size is 8 mm in diameter and 20 mm in height. The quartz plate is 6 mm in diameter and 1 mm in thickness. The cell is connected to a micro valve for pressure control. The height and diameter of the entire system inside this scanner cannot be more than 85 mm and 50 mm, respectively. Aluminum was chosen as the cell body material due to its X-ray transparency and ability to withstand the elevated pressure at the experiment temperatures. The maximum temperature that can be reached in the cell is 120^{o}C under the experimental pressure.

The contact angle for the system of quartz-water (brine)-bitumen is measured at different temperatures and pressures for four different cases; (1) water is the drop, bitumen is the bulk phase and the quartz surface is exposed to bitumen before the drop is placed on it; (2) water is the drop, bitumen is the bulk phase, the drop is placed on the quartz surface first followed by the bitumen filling the cell; (3) bitumen is the drop, water is the bulk phase and the drop is placed in the quartz surface before water filling the cell, and (4) bitumen is the drop, water is the bulk phase, the quartz surface is exposed to water first and then a drop of bitumen is placed on the surface.

The brine used for this study is a 20 wt% $CaCl_2$ solution. In order to produce clear interfaces in the micro-CT images, bitumen is mixed with 1-Iododecane. The concentration of this additive in the bitumen is 4% vol. Although the presented fluid pairs and experimental conditions are not yet matched for thermal operations, they are used for the development of the methodology, which will then be expanded to more realistic conditions.

RESULTS AND DISCUSSIONS

Case 1:

The system undergoes different pressures and temperatures and in each stage a micro-CT image of the interface is taken. The results are shown in Figure 1.

As pressure increases the contact angles become smaller and therefore, the system turns from weak oil-wet to intermediate wettability. As it can be seen in the figure, at ambient pressure the range of contact angles is 130^o to 140^o and at 1000 psi the contact angles are mostly in the range of 100^o to 110^o that is less oil-wet. When the pressure changes from 200 psi to 800 psi the contact angle does not change as dramatically. In each pressure, the contact angle decreases as the temperature increases, this means the system becomes more water-wet at elevated temperatures.

Case 2:

The contact angles are totally different to those from case 1. Figure 2 presents these results. In this case, the quartz is clearly water-wet. In reality, the reservoirs were exposed to the connate water first and subsequently the oil was produced and entered the reservoirs.

Therefore, the results from case 2 introduce a more similar situation to what is encountered in the reservoirs.

Analogous to case 1, as the pressure and temperature increase the contact angle becomes smaller and the quartz shows more water-wet affinity.

In case 2, two drops of water with different diameters (1 mm and 2.5 mm) were studied. The results of contact angle measurements at different temperatures for 200 psi, 400 psi, 600 psi, and 1000 psi are illustrated in Figure 3 to Figure 6. The contact angles measured for the smaller drop (1 mm diameter) are generally smaller than the bigger drop (2.5 mm diameter) at all studied pressures.

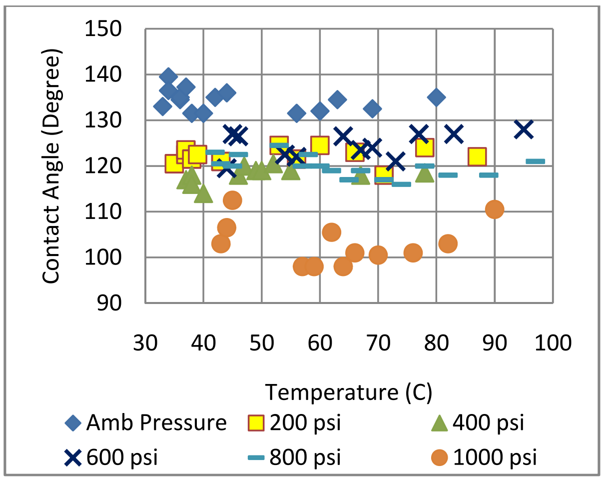

Figure 1. Results for case 1 at different temperatures and pressures

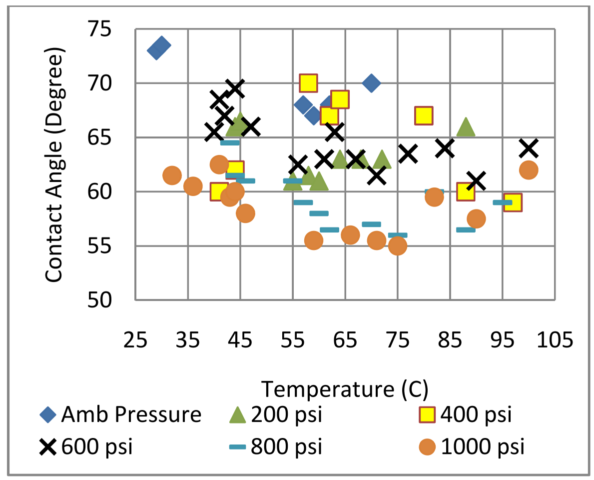

Figure 2. Results for case 2 at different temperatures and pressures

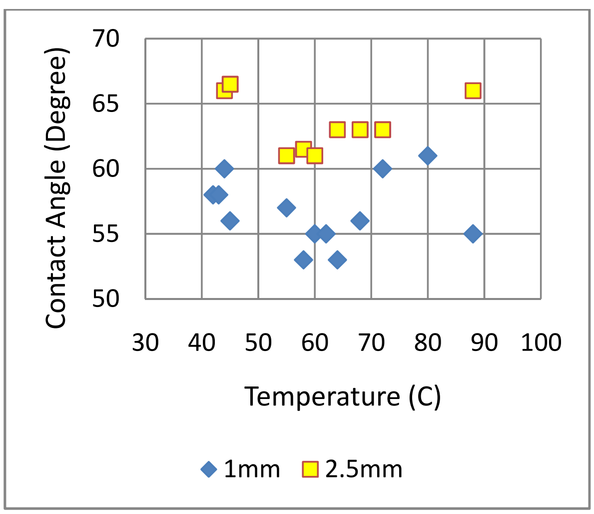

Figure 3. Effect of drop size on contact angle values for different temperatures at 200 psi

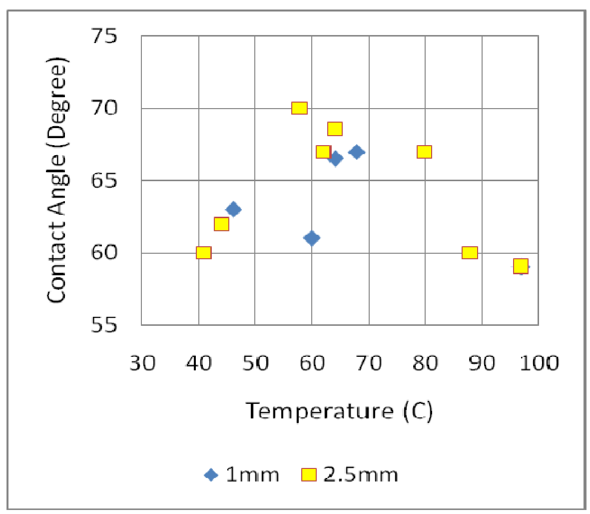

Figure 4. Effect of drop size on contact angle values for different temperatures at 400 psi

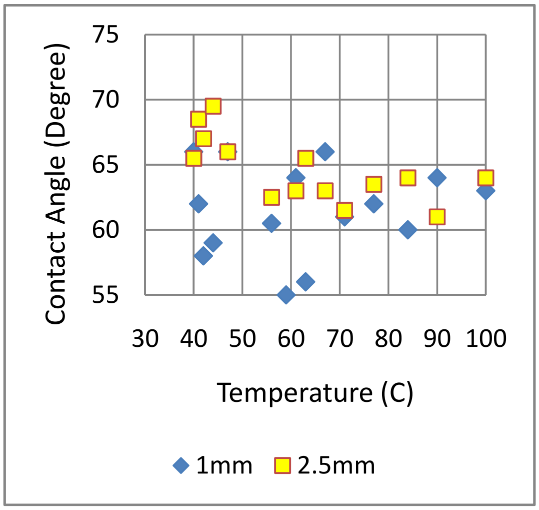

Figure 5. Effect of drop size on contact angle values for different temperatures at 600 psi

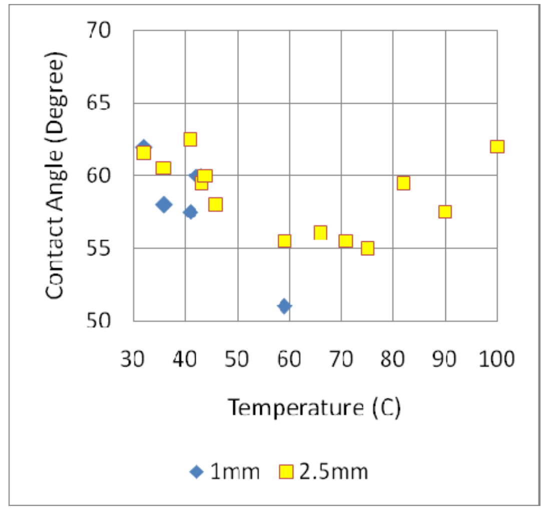

Figure 6. Effect of drop size on contact angle values for different temperatures at 1000 psi

Case 3:
The results in figure 7 show that increasing pressure from 500 psi to 1000 psi decreases the (θ) and therefore the system turns toward water-wetness. The results for ambient pressure do not follow this trend. Also, in both 500 psi and 1000 psi the (θ) decreases as the temperature goes up and therefore, the system tends to move toward intermediate wettability from its initial oil-wet characteristics.

Case 4:
The result trends in the test of different pressures and temperatures in this case show no comparability to the other three cases. The results are illustrated in Figure 8.

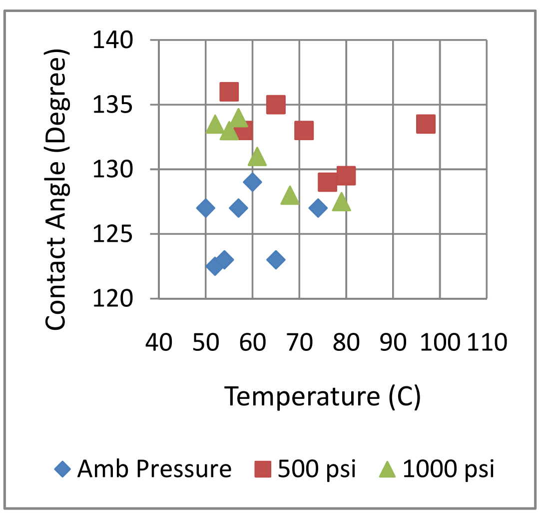

Figure 7. Results for case 3 at different temperatures and pressures

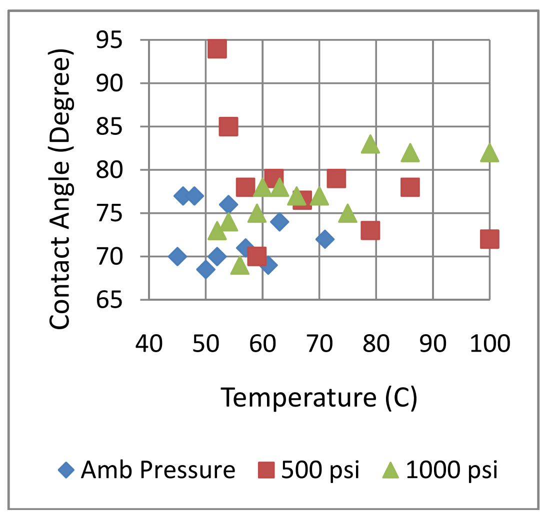

Figure 8. Results for case 4 at different temperatures and pressures

CONCLUSIONS

1. The studies on temperature changes show that in general the system goes more water-wet as the temperature increases. Although these changes are not very significant, the trend of the curves shows this fact in all the cases.

2. In most of the cases, when the pressure goes up, the quartz surface shows more water-wet characteristics comparing to the lower pressures. The results at 1000 psi show the wettability changes to more water-wet more clearly.

3. From the results of all four cases it is evident that the order of substance exposure affects the wettability characteristics of the system. When the surface is exposed to water first, it shows a water-wet property and vice versa. That is because the minerals in water and the polar molecules in oil can adsorb on the surface of the solid and change the wettability of the surface.

4. In general, the quartz surface is more oil-wet. When the system is exposed to water first, the contact angle is closer to 90^o (neutral wettability) than when it is exposed to oil first.

5. As the water drop becomes smaller, it spreads easier over the quartz surface and therefore, there is a smaller contact angle for the quartz-water drop-bitumen system. Therefore, the system is more water-wet when the water drop size decreases.

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