Molasses Affects Surface and Interfacial Forces, pH, and Phase Behavior of Crude Oil–Brine System

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ABSTRACT

In this work the effect of molasses, as a bacterial nutrient, on the pH and surface tension of the aqueous phase, IFT, and phase behavior after one-week contact time was studied at 60°C. The results have shown that the pH value and surface tension of molasses solution as well as IFT have the same trends versus salinity. These properties as well as the phase behavior are function of NaCl concentration, contact time, pressure and initial pH value of the molasses solutions.

INTRODUCTION

MEOR is a potentially attractive way to recover additional oil from a reservoir beyond conventional operations [1–3]. The process is inexpensive and has advanced from laboratory based studies [4–21] to field applications [22–27]. Microbial enhanced oil recovery (MEOR) process design requires the integrated efforts of biological, chemical, and petroleum disciplines in order to become a fully developed enhanced oil recovery technology.

MEOR can occur through in situ formation of normal metabolic products that result from the use of a nutrient by reservoir microorganisms or specially selected natural bacteria. In this case the MEOR fluid system consists of a nutrient or a nutrient and microbes. The nutrient is to feed the bacteria and is injected into the reservoir with and before bacteria by an interval of time that may reach one-week [27]. Then the time span between the molasses solution injection and the microbe injection into the reservoir in case of injecting them separately is one- week. This is also nearly the time span required for adaptation of bacteria to reservoir conditions. Then after one week and higher contact times, the microbial products affect the measured properties. Therefore, the conditions in the reservoir after one week from molasses injection into the reservoir represent the conditions encountered by the microbes during their injection or adaptation. The metabolic products produced by bacteria are gases, acids, low molecular-weight solvents, surfactants and polymers. These products affect the oil and water properties, the interfacial tension (IFT) between the oil and water, and the phase behavior of oil-water-overall microbial system; and cause additional oil recovery beyond conventional operations.

In the previous studies the effect of the overall system components (nutrient, microbes, and microbial products) on the MEOR process was studied. Some of these studies [6–8,10–13] used molasses as a microbial nutrient. Although it is assumed that fermentation of sugar such as sucrose in molasses by microorganisms causes the production of chemicals that can improve oil mobilization, the actual chemical and the mechanisms involved in this process have not been fully identified. The effect of the overall system components containing molasses on the pH [8, 10, 11, 13], surface tension [7, 11], interfacial tension (IFT) [7, 8, 10, 11, 13] and phase behavior [7, 8, 12] was studied in the laboratory at different temperatures and one atmosphere pressure. However, the individual and combined effects of the separate components of the system on the pH, surface tension, interfacial tension (IFT) and phase behavior at ambient and reservoir conditions were not investigated. In this study, in the absence of bacteria, the effect of molasses as a microbial nutrient on the pH, surface tension of the aqueous phase, and the phase behavior was studied. The effect of the following parameters on these properties was investigated: (i) molasses concentration, (ii) NaCl concentration, (iii) pressure, and (iv) initial value of the pH.

EXPERIMENTAL WORK

The laboratory study in this work was divided into two parts. The first part was to study the effect of the previously mentioned parameters on the IFT between the molasses solutions and Ratawi crude oil, and the surface tension and the pH of the molasses solutions. The second part was to investigate the effect of molasses solutions on the phase behavior of Ratawi crude oil – molasses solutions at atmospheric and reservoir pressures, and at different salinity and pH.

The API degree of Ratawi crude oil is 32.3, and the viscosity at 25°C and 60°C are 10.7 and 4.4 cp, respectively. Inorganic acid

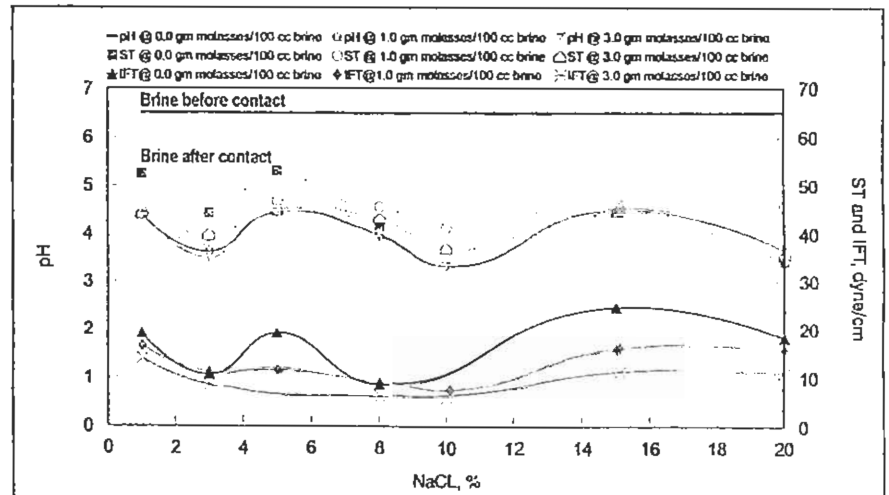

Fig. 1 Effect of NaCl concentration on the pH and surface tension of the molasses solutions and IFT at different molasses concentrations after one week contact time at [illegible]

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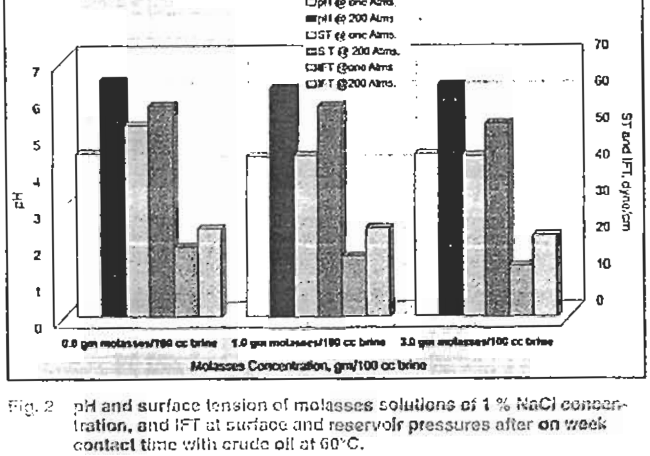

Fig. 2 pH and surface tension of molasses solutions of 1 % NaCl concentration, and IFT at surface and reservoir pressures after on week contact time with crude oil at 60°C.

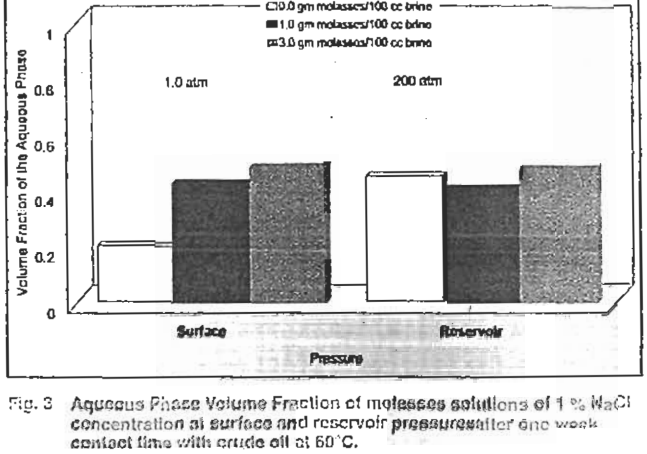

Fig. 3 Aqueous Phase Volume Fraction of molasses solutions of 1 % NaCl concentration at surface and reservoir pressuresafter one week contact time with crude oil at 60°C.

content of the crude oil was determined using the IP 182 method with the modification of measuring the pH of the water phase instead of titration with potassium hydroxide solution. Inorganic acids include all substances that can be extracted from crude oil with water and react with alkali under the conditions of the test. The pH of the distilled water before mixing with crude oil was 7.0 and after separation it was 3.59.

It is worthwhile to mention here that the used fluids were analyzed, in three different laboratories, for bacterial content before and after mixing and equilibration; it was found that there were no bacteria in the used solutions through out this work. The surface and IFT were measured by using the ring method. The readings were displayed in dyne/cm. The sample vessel was cleaned before each measurement. Equal volumes of oil and molasses solutions were put in graduated cylinders. The oil and the molasses solutions were separated using a syringe after they had been shaken and left to equilibrate for predetermined time (contact time one week) at the required temperature and pressure.

RESULTS AND CONCLUSIONS

1. At any molasses concentration, the pH and surface tension of the molasses solutions as well as the IFT have the same trends versus salinity. In Fig. 1 the pH and surface tension of the molasses solutions, and the IFT is plotted versus NaCl concentration at molasses concentrations of zero, 1.0, and 3.0 g/100 cm^3 brine. Normally, NaCl does not affect the pH value of the solutions before contact with the crude oil. However, after one week contact time, the NaCl concentration affects the pH and surface tension of the molasses solutions as well as the IFT. This effect may be attributed to the transportation of some acidic components from the crude oil to the molasses solutions. The NaCl and molasses affect the partitioning of the acidic components transported from the oil to the aqueous phase, the formed emulsion phase, and the interface between the oil and aqueous phases.
2. At molasses concentrations of zero, 1, and 3 g/100 cm^3 brine, the pH, surface tension and IFT increased as the pressure increased from the surface pressure (1.0 atm) to the reservoir pressure (200 atm) after one-week contact time; see Fig. 2. This means that, in this case, acidic components transported from the aqueous phase to the oleic phase. This is the opposite of that happened at 1.0 atm as the contact time increased from zero to one week. This indicates that the partitioning of the system components is a strong function of pressure. The increase in the surface tension is due to the change in the aqueous phase composition that is approved by the change in the color of the aqueous phase to dark and the increase in the pH as the pressure increased to 200 atm. The increase in the IFT with pressure is attributed to the change in the composition of the crude oil, molasses solution, and interfacial layer during the equilibration processes due to the partitioning of the system component in the aqueous phase, oleic phase, and at the interfaces.
3. After one-week contact time, the aqueous phase volume decreased; the volume fraction of the aqueous phase is less than 0.5. This reduction is almost constant in the presence of molasses; in the absence of molasses, the pressure largely affects the aqueous phase volume. The volume change at surface and reservoir pressures, after one-week contact time, is plotted in Fig. 3.
4. The initial pH of the molasses solutions affects the surface tensions of the molasses solution, and the IFT as well as the volume fraction of the aqueous phase after one-week contact time. The surface tension, IFT, and the volume fraction of the aqueous phase versus molasses concentration of 3% NaCl at one atmosphere and 60°C are plotted in Fig. 4. The figure indicates that the plotted values depend

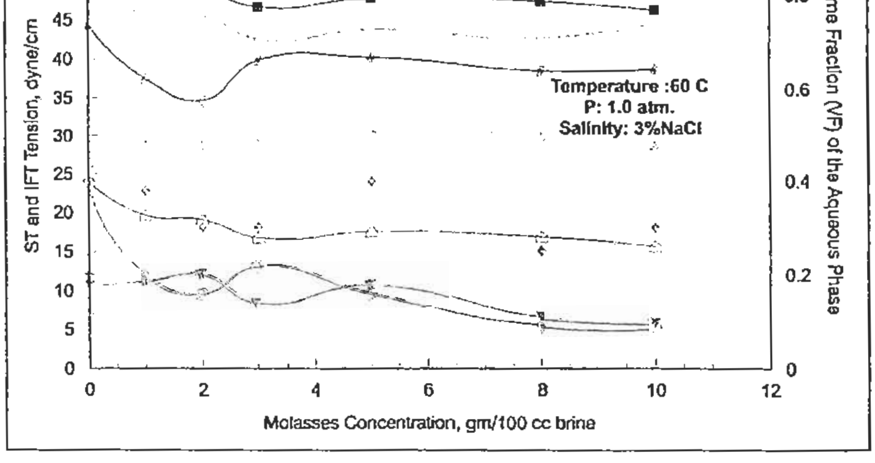

Fig. 4 Effect of the initial pH value of 3 % NaCl molasses solutions on the surface tension of the molasses solutions and IFT, and volume fraction of the aqueous phase after one week contact time at 1.0 atmosphere and 60°C.

on the initial pH. There are changes in the composition of both the aqueous phase, the crude oil, and interfacial film due to the change in initial pH of the molasses solutions. The size of the formed emulsion increased as the initial pH of the molasses solutions increased from 7 to 9.2.

5. The sinusoidal effect of salinity needs more investigation.

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