J. Adhesion Sci. Technol., Vol. 9, No. 4, pp. 425–431 (1995)

Effect of microorganisms on rock wettability

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Received in final form 25 July 1994

Abstract—The principal objective of this investigation was to study the effect of microorganisms on rock wettability behavior. Crude oil was used to measure the contact angles both at 23 and 50°C on solid rock samples. It was found that the bacteria obtained from crude oil had an effect on contact angles at both 23 and 50°C. This effect depends on the type of nutrient used, type of rock sample, type of microorganism, and temperature at which the experiments were carried out.

Keywords: Microorganism; rock wettability; bacteria; crude oil.

1. INTRODUCTION

Bacteria are the only microorganisms that have been proposed for use in enhanced oil recovery processes. They are small, grow exponentially, and they produce metabolic compounds such as gases, acids, surfactants, and polymers [1–4].

Many species of microorganisms produce carbon dioxide and other gases such as nitrogen, hydrogen, and methane. Because many types of microorganisms produce polymers, they have been used to plug high-permeability zones in a petroleum reservoir to improve sweep efficiency. Microbes also produce low molecular-weight acids, primarily low molecular-weight fatty acids, that can improve the permeability of rock for increasing oil production.

Microorganisms also produce biosurfactants that can decrease the surface and oil-water interfacial tensions to as low as 5×10^{-3} mN/m which causes emulsification [5]. Microbes have been shown to alter the wettability of glass micromodels and Berea Sandstone [6]. In 1986 Kianipay and Donaldson [7] found that *in-situ* microbial growth mobilized the residual oil by reversing the wettability of rock from oil-wet to water-wet.

This study concentrated on evaluating the alteration of wettability obtained as a result of contact between sandstone or limestone surface and metabolic compounds produced by microorganisms.

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2. WETTABILITY EVALUATION

Sandstone and limestone samples 1.6 inch (4 cm) in diameter and 0.8 inch (2 cm) in length with a very smooth surface were used as substrates to measure the contact angles. Some of the samples' characteristics are given in Table 1. Toluene saturated with water and methanol and pure toluene were used for cleaning the samples. The samples were then dried, evacuated and saturated with aqueous solution (normal saline, 1% NaCl).

The oil droplet from which the bacteria was isolated was placed in contact with a downward highly smoothed rock surface (see Fig. 1) and then immersed in the same bacterial aqueous solution (a culture of selected bacteria strain suspended in sterile normal saline, 1% sodium chloride) in a glass container.

The droplet was photographed at different time intervals to study the change in the contact angle with time, until equilibrium was reached. Equilibrium was indicated when no change in the shape of the drop was observed. The contact angle in the water phase was determined by making tangents to both sides of the oil droplet (i.e. the

Table 1.
Characteristics of rock samples used in contact angle measurements

Property	Rock type	
	Sandstone	Limestone
Length, cm	2	2
Diameter, cm	4	4
Porosity, %	22	7
Absolute permeability, mD	470	70

mD = Millidarcy.

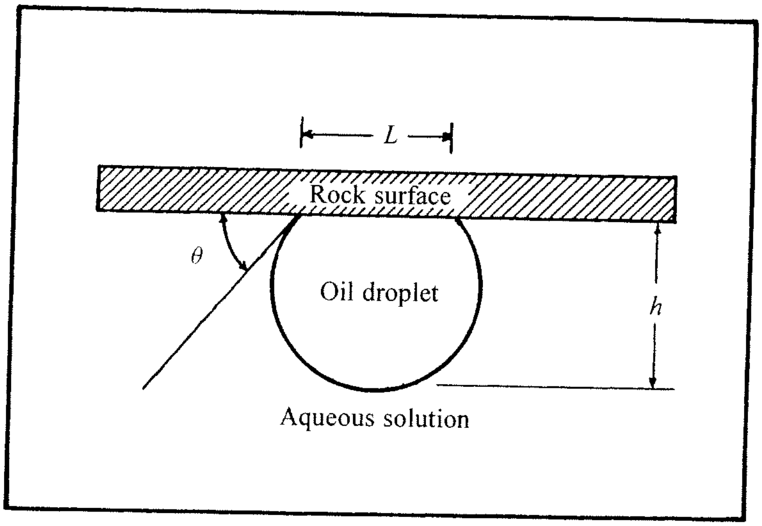

Figure 1. Contact angle measured through the bacterial phase.

contact angle taken from the tangent is that angle drawn through the oil phase). The precision obtained when the contact angle was evaluated using the tangent obtained on the photograph was with $\pm 1°$.

Two species of bacteria were used. The O_9 solution was isolated from Safaniyah crude oil while the bacterial solution O_{6a} was obtained from Khafji crude oil. The properties of the solutions are given in Table 2. A Genco du Nouy tensiometer was used to determine the interfacial tension between oil and bacterial aqueous media given in Table 2.

Three different bacterial nutrients — glucose, sucrose, and molasses — were used in the present study. The concentration of molasses in distilled water was 1% by volume. The composition of glucose and sucrose solutions is shown in Table 3.

Table 2.
Properties of bacterial solutions

Type of bacteria	(Clocci) O_{6a}	(Clocci) O_9
Gm	+	+
pH	6.68	7–8
Surface tension (mN/m)	34.4	56
*IFT (mN/m)		
From	21.38	21.25
To	17.8	16.85
Viscosity (cp)	1.31	1.25
Oxidation	Alk	+
Growth in		
$+O_2$	+	+
$-O_2$	+	+
Fermentation	Alk	+

Gm = Gram Stain.
$+O_2$ = In presence of Oxygen.
$-O_2$ = In absence of Oxygen.
Alk = Alkaline Reaction.
IFT = Interfacial Tension.
*Method of measurement is shown in experimental section.

Table 3.
Composition of glucose and sucrose solutions

Tryptone (oxide)	= 0.29 g
Yeast extract	= 0.2 g
Sodium chloride (oxide)	= 0.1 g
Ammonium sulfate	= 0.1 g
Magnesium sulfate	= 0.025 g
Glucose or sucrose	= 1.0 g

3. RESULTS AND DISCUSSION

The investigation of the ability of microbial systems to alter the rock wettability is important. To reach this objective the effect of microorganisms on rock wettability was studied.

Figure 2 shows that the molasses tends to change the rock wettability towards water-wet at 23 °C for limestone. However, almost the same contact angle was obtained for both sucrose and molasses solutions when using sandstone surface at 50 °C (Fig. 3). This effect may be attributed to the molasses solution properties of emulsifying compounds that may be present. These compounds tend to lower the contact angle. On the other hand, the effect of nutrient type on the distribution of biomass generated on the surface of the rock sample may change the wettability. This change is related also to the type of the rock surface. Bacteria cells have certain characteristics, such as electrical surface charge and capability to concentrate ions at high concentration on their surfaces, that increase their probability of affecting rock-water interactions. Figure 4 shows that lower contact angles were obtained when using limestone surface.

Figure 4 also shows the effect of different bacterial solutions (5% O_9 in glucose, 5% O_{6a} in glucose, and 5% O_9 in sucrose) on the contact angle at 23 °C. It is seen that O_{6a} tends to make the limestone surfaces more water-wet. However, at higher temperature (50 °C) the type O_9 tends to make the surface more water-wet due to the growth behavior of bacteria.

Figures 4 and 5 show the variation of contact angle with time at 23 and 50 °C. It is seen that equilibrium contact angle can be achieved earlier at higher temperature.

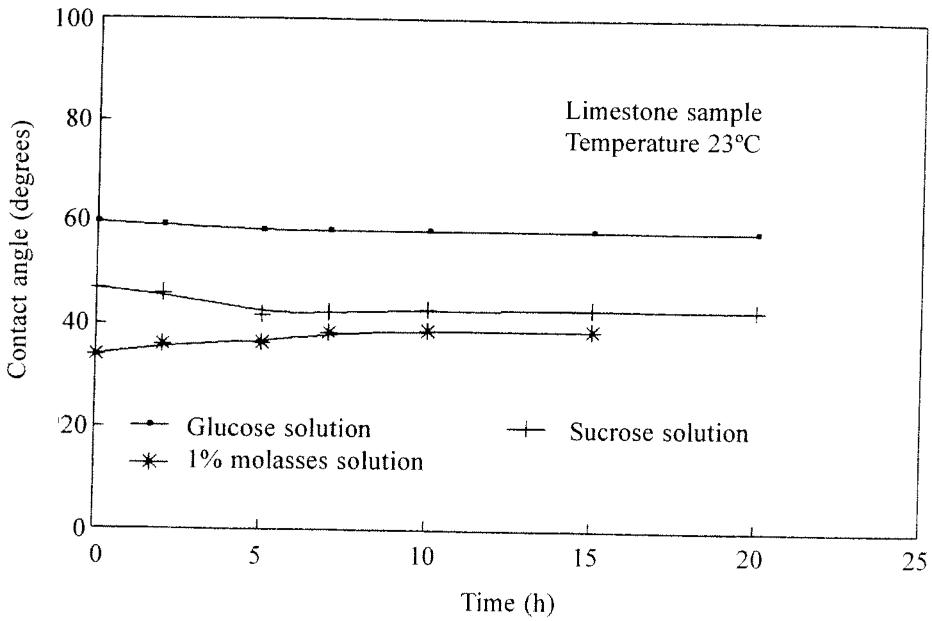

Figure 2. Contact angle vs. time for different nutrients at 23 °C.

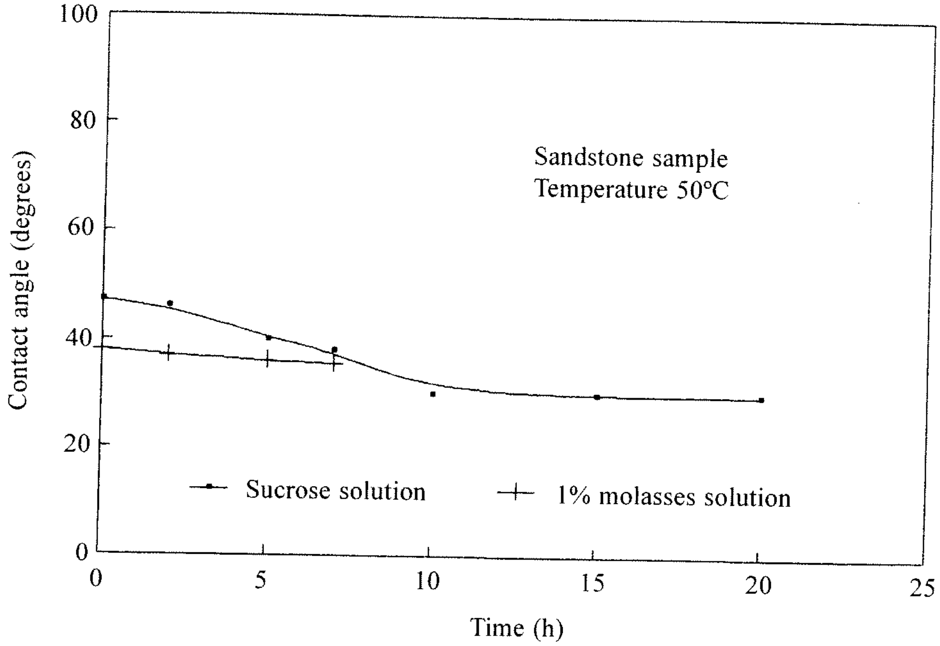

Figure 3. Contact angle vs. time for different nutrients at 50 °C.

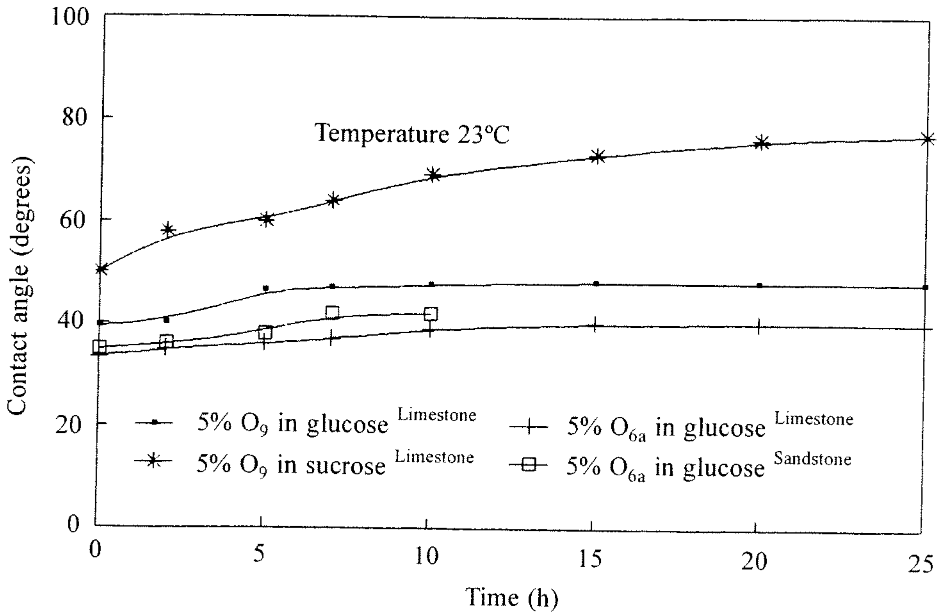

Figure 4. Contact angle vs. time for different bacterial solutions at 23 °C.

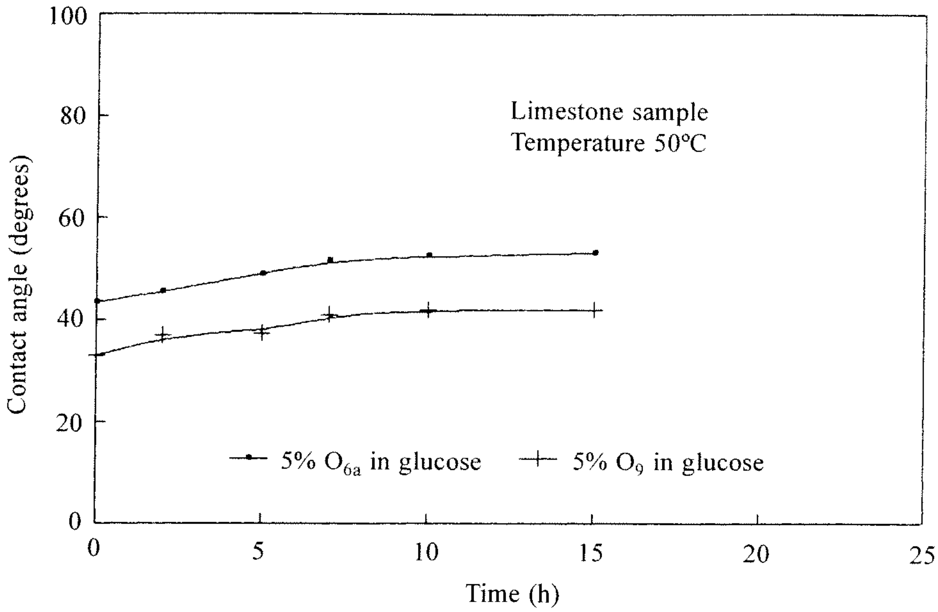

Figure 5. Contact angle vs. time for different bacterial solutions at 50 °C.

This behavior is basically due to the effect of higher temperature on the biological activities of the microorganisms.

4. CONCLUSIONS

During the growth of bacteria, nutrients are consumed and several metabolites such as gases, acids, alcohols, surfactants, polymers, etc. are produced. The type of metabolite depends on the type of bacteria and nutrient used. Therefore, this will affect the rock wettability characteristics. A better understanding of the mechanisms of wettability alteration is necessary for selecting appropriate bacterial strains, thus designing optimal operational procedures. Unfortunately, because of the complex interaction among the microorganisms, the reservoir surface, the aqueous phase, and the oil, the complete elucidation of the role of the microbial activities is no simple matter and will probably require intensive research for several years.

Based on the results obtained in this work, the following conclusions are drawn:

1. The species of bacteria used has an effect on the contact angle at both 23 and 50 °C. This effect depends on the type of nutrient used.
2. Molasses tends to decrease the contact angle of oil at both 23 and 50 °C on limestone as well as sandstone samples.
3. The equilibrium contact angle was achieved at both 23 and 50 °C using different bacterial solutions after about 7 h in most cases.
4. Contact angle was lower when using limestone than sandstone core with O_{6a} bacteria.

Acknowledgement

The authors would like to thank S. Desouky and A. Al-Ghamdi for their help in experimental measurements. Thanks are also due to Dr H. Shoabe from the Microorganism Department for supplying the bacterial solutions.

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