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EFFECT OF CLAY CONTENT ON WETTABILITY OF SANDSTONE RESERVOIRS

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Abstract

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Synthetic consolidated sandstone cores with different clay contents were used to study the effect of clay mineralogy and percentage on the rock wettability. The effect of salinity and alkalinity on wettability was investigated with, as well as without, polymers.

Contact angle increased with increasing clay content when 0 and 35,000 ppm NaCl solutions were used; however, when a very high-salinity solution was used, the contact angle decreased with increasing clay content. The presence of an alkaline salt in a high-salinity solution made the system preferentially oil-wet. The same effect was obtained when a polymer was added to the solution. Clay content had no effect on contact angle in the presence of polymers.

Introduction

The wettability of a rock may affect almost all core analyses, including capillary pressure, relative permeability, waterflood behavior, electrical properties, and secondary and tertiary recovery processes. Reservoir wettability can be changed by adsorption of polar compounds and/or the deposition of organic matter originally in the crude oil or by surface-active agents injected during enhanced oil recovery processes. The adsorption of these compounds is normally affected by the presence or the absence of clays in the cores.

Preferential adsorption of the high equivalent weight sulfonates on montmorillonite have been observed (Gale and Sandivk, 1973). Adsorption increase has been observed on cores having a higher content of clays (Hower, 1970; Coke et al., 1974, Malmberge and Smith, 1976; Soassundaran and Hanna, 1978). The nature of reservoir wettability is dependent on the presence or absence of polar compounds, apparently asphaltic in nature, adsorbed on the rock surfaces; they then to make these surfaces oil-wet. The effect of these polar compounds depends to some degree on the nature of the rock surfaces (silica, carbonate, or clay). The active surface chemistry in the case of clays increases this effect more than in silica or in carbonates.

Several studies have been made regarding the adsorption of asphaltenes and resins onto clays, and found that adsorption can make the clay more oil-wet (Somenon and Rodke, 1983). Clementz (1976; 1977; 1982) found that some compounds can be adsorbed rapidly onto montmorillonite, forming stable clay-organic compounds and changing the wettability from water-wet to oil-wet. The adsorption also re-

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duced the expansion of swelling clays, clay surface area, cation exchange capacity, and water sensitivity; however, the adsorption of asphaltenes on Berea sandstone cores in the presence of water did not reduce water sensitivity of the kaolinite contained in the core (Clementz, 1977). Reviews of the effect of wettability on electrical properties, capillary pressure and relative permeability of the porous media have recently been published (Anderson, 1986a,b,c, 1987a,b,c).

The objective of this study was to investigate the effect of shale content on wettability characteristics of Saudi sandstone reservoirs, which was accomplished in the following manner: (1) mechanical and mineralogical analyses of two types of Saudi sandstone cores to determine the amount and type of clay and non-clay minerals: (2) studying the effect of clay content on the wettability of synthetic sandstone cores having the same mineralogical composition as the actual core; and (3) investigation of the effect of water salinity, alkalinity and polymer on rock wettability in the presence of clays.

Materials and methods of characterization

Two types of Saudi sandstone cores were used: (1) Alkhafji cores obtained from wells in the Alkhafji producing area in the northeastern part of the Kingdom of Saudi Arabia and (2) Aramco cores obtained from wells in the Aramco production area in the eastern part of the Kingdom.

Analysis of the cores were made after soaking the cores in hot water for 24 h. Oriented clay films of the clay fractions were prepared on glass slides after drying at 40–50°C. The slides were analysed with a Philips X-ray refractometer with a graphite monochromator and a Cu-target X-ray tube operated at 35 kV and 15 mA. Non-clay minerals were identified with a petrographic microscope. The structure of the clays was determined using a Zeiss Em 109 electron microscope. Clay fractions were analyzed using HF dissolution and elemental determinations by atomic absorption using acetylene and nitrous oxide gases.

The wettability measurements were made by the contact angle method in the absence of air with no metal parts. Figure 1 shows a schematic diagram of the apparatus used for measuring the contact angle between crude oil and the formation water at a temperature of 60°F. A camera with a slide film was used to take photos of the oil droplet. The oil droplet was contacted with a very smoothed surface of sandstone rock immersed in formation water. The oil droplet was photographed at periodic time intervals (1 h) to monitor the change of the contact angle with time until equilibrium was reached. Equilibrium time at 60°F was about 24 h. The contact angle was then directly measured from the photographs.

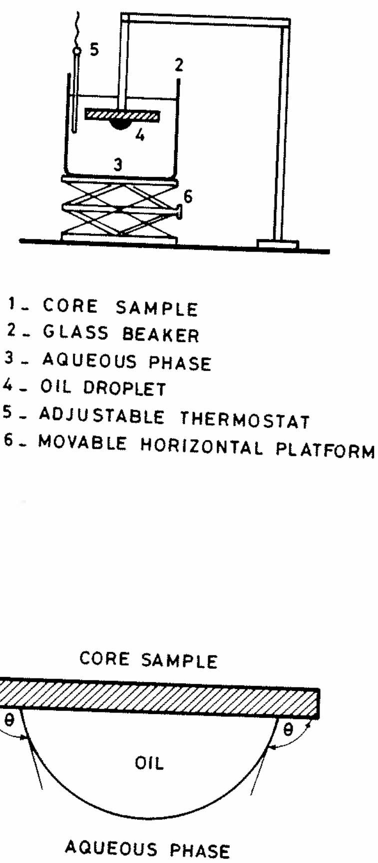

Fig. 1. Contact angle measurement.

Results and discussions

The mechanical analyses of the cores are presented in Fig. 2. The mineralogical composition is shown in Fig. 3 and listed in Table 1. The clay content in the cores ranges from 2 to 8%. The cores consist essentially of quartz (>85%), and associated non-clay minerals are mainly feldspars and pyrite.

The X-ray analyses of the cores showed that the clay fractions consist mainly of kaolinite. Some cores contain chlorite and others contain interstratified illite–montmorillonite minerals.

The electron micrograph of the clay fraction (Fig. 4) indicates clearly the presence of disordered kaolinite. The edges of the flakes are somewhat ragged and irregular, and the hexagonal outline is not well formed, with occasional presence of twinned particles. It was difficult to locate the interstratified minerals in the micrograph because of the small amounts present.

To study the effect of the presence of clay in sandstones on wettability, synthetic sandstone samples (similar to actual cores) were used to simulate the rock, and the contact angles of the oil/water interface with the rock surface measured in an aqueous phase were determined. The results are shown in Fig. 5 using different concentrations of NaCl; 35,000 ppm NaCl is representative of seawater which is frequently used for injection and 250,000 ppm NaCl represents the equivalent composition of formation reservoir water. All measurements were carried out at an ambient temperature of 60°F. Each point on the curve in each figure is the average of two measured values on both sides of the oil droplet. The measured contact angle using different solutions was based on the contact angle measured after attainment of equilibrium. The effects of adding 0.5% NaOH and Pusher-700 polymer to a 35,000-ppm NaCl solution on the contact angle measurements at different clay contents are shown in Figs. 6 and 7. It is clear that there is a large effect of clay content on rock wettability in the presence of alkaline solutions. The hydroxide ions of NaOH solution may react with the organic acids in the crude oil, forming natural surfactant which could be adsorbed on the rock surface changing its wettability.

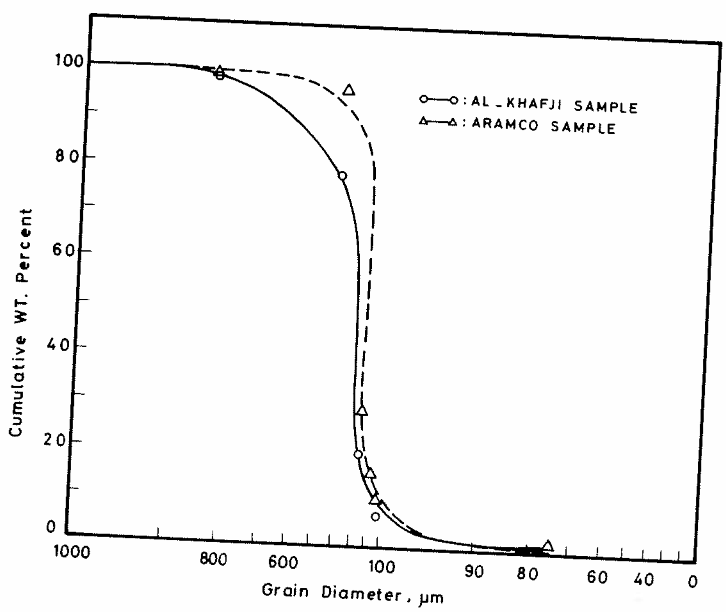

Fig. 2. Cumulative weight percent versus grain size diameter.

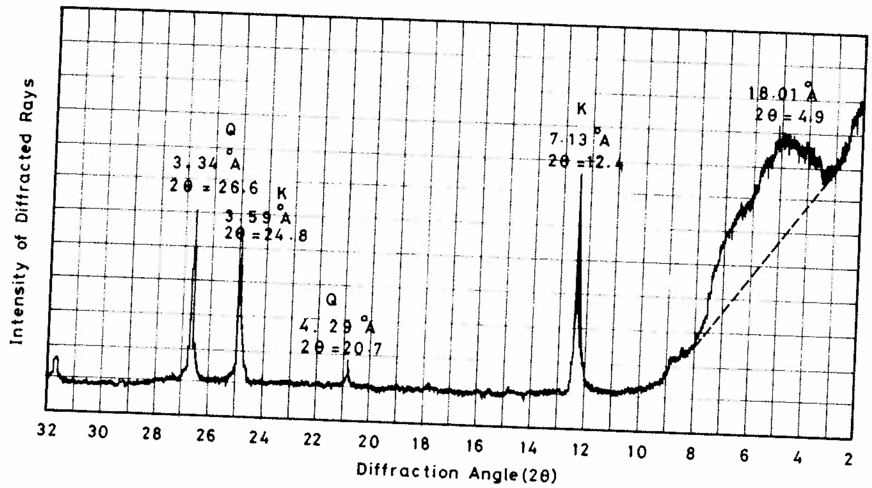

Fig. 3. Mineralogical analysis of clays in Al-Khafji sample.

TABLE 1

Analyses of sandstone cores

	Mineralogical composition (% wt)				% Relative abundance of clay families				
	quartz	feldspars	other minerals	clays	Kaolinite	Chlorite	Illite	Montmorillonite	Interstratified minerals
Al-Khafji (1)	94.8	2	1.0	2.2	70	–	–	Traces	28
Al-Khafji (2)	92.0	2	1.0	5.0	69	35	–	–	–
Aramco	85.0	3	4*	8.0	40	27	17	6	–

*Mainly pyrite.

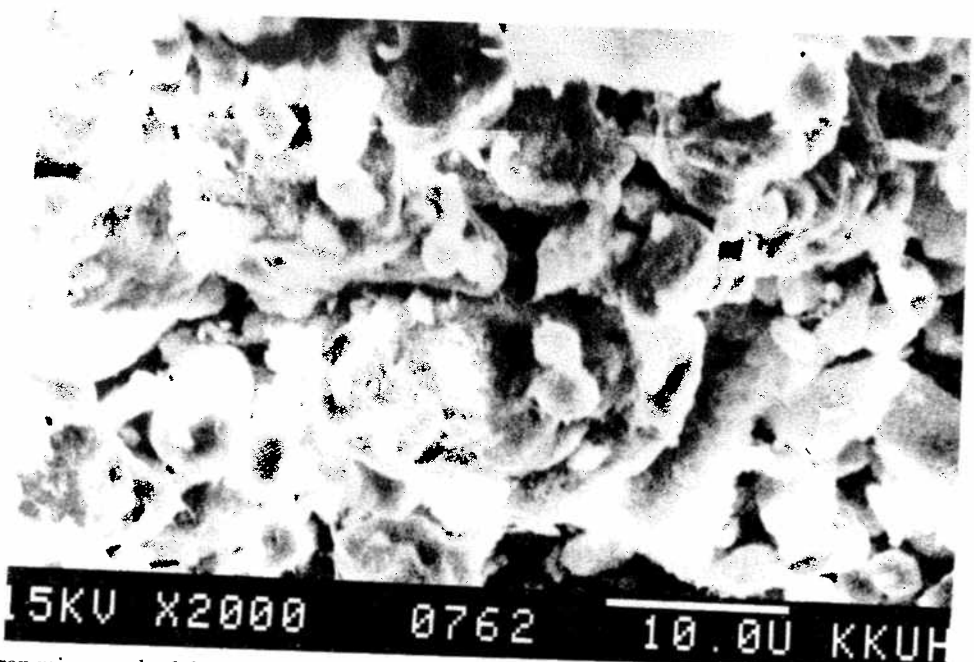

Fig. 4. Electron micrograph of the clay fraction showing presence of disordered kaolinite.

Effect of clay content on rock wettability using NaCl Solutions having different concentrations

The following discussion is an effort to systematically examine the effect of clay content on rock wettability for the experimental conditions used. Fig. 5 shows the effect of clay content on contact angle using distilled water as the aqueous phase. The contact angle increases with increasing clay content. Increasing contact angle with higher values of clay content may be explained by the possible formation of clay-organic compounds due to rapid adsorption and the possible swelling of clays in distilled water. Swelling causes more spreading of the oil droplet on the surface. The same behavior is observed with 35,000 ppm NaCl solution as an aqueous phase (see Fig. 5). The contact angle increases with increasing clay content. In this case swelling is partially inhibited by the presence of salt; however, the formation of clay-

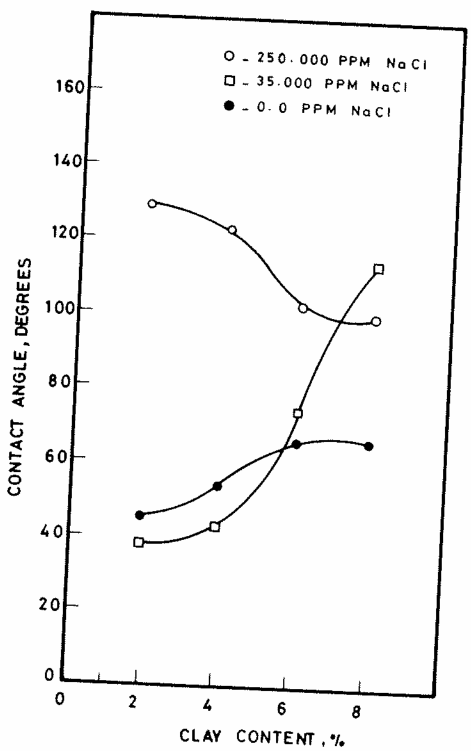

Fig. 5. Effect of clay content on contact angle using 0; 35,000; and 250,000 ppm NaCl solutions.

organic compounds is dominant and hence increases the contact angle. At higher clay content, the effect of clay swelling is more dominant. This will lead to an increase in contact angle as explained before.

In the case of using a very high concentration of NaCl solution (25% NaCl), precipitation of salt may occur on the surface of the core balancing the effect of clay swelling. Hence, the contact angle decreases with increasing clay content as shown in Fig. 5.

Effect of clay content on contact angle using alkaline solutions

The presence of NaOH should activate the surface of clays causing higher cation exchange capacity which increases the adsorption of water on the clay surface. The contact angle (as shown in Fig. 6) decreases with increasing clay content up to a point, then it increases with further increase of clay content when using 0.5 and 1% NaOH concentrations. This means that the system is preferentially water-wet, and at higher values of clay content the system tends to be preferentially oil-wet. The same figure shows that the contact angle increases with increasing NaOH concentration in the aqueous phase which agrees with the findings of Wagner and Leach (1959). The hydroxyl ions probably adsorb on the clay surfaces and increase their negative charges causing the clay particles to repulse each other to become better dispersed. Sodium ions of NaOH cause more swelling as a result of base exchange. The presence of excessive sodium (when using 1% NaOH), causes the contact angle to increase because of neutralization of negative charges on clay surfaces by the Na^+ cation.

Effect of clay content on contact angle in the presence of polymer solutions

The effect of the presence of a polymer in 35,000-ppm NaCl solution; and 0.5% NaOH solution is shown in Fig. 7. In this case the poly-

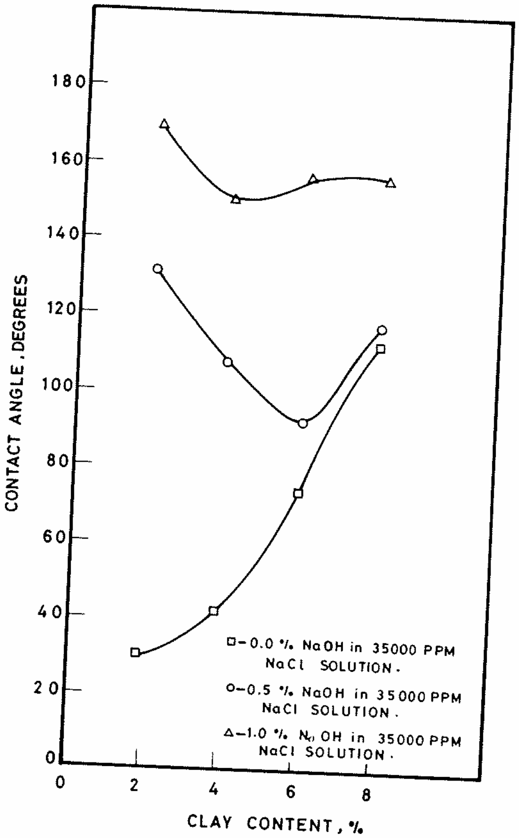

Fig. 6. Effect of clay content on contact angle using 0, 0.5 and 1% NaOH solutions.

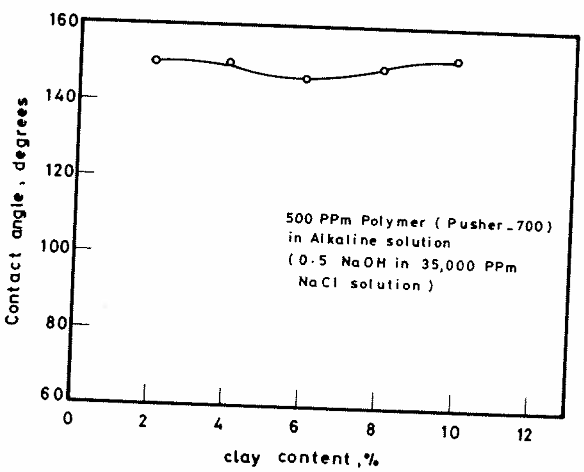

Fig. 7. Effect of clay content on contact angle in the presence of polymers.

mer adsorbed on the surface of the reservoir rock tends to make these surfaces preferentially oil-wet (i.e., high contact angle was obtained). Also, the presence of polymer may isolate clay particles existing on the rock surface and hence no effect of clay content on the variation of contact angle was observed as shown in Fig. 7.

Conclusions

From this investigation following conclusions are drawn:

(1) The contact angle increases with increasing clay content when using distilled water and 35,000-ppm NaCl solution as an aqueous phase.

(2) Using very high concentrations of NaCl solution (250,000 ppm) as an aqueous phase, the contact angle decreases with increasing clay content.

(3) When adding NaOH to 35,000-NaCl solution, the system is preferentially oil-wet at all values of clay content. Contact angle increases with increasing NaOH concentration in the aqueous solution.

(4) No effect of clay content on contact angle was observed in the presence of a polymer. The presence of a polymer in 35,000-ppm NaCl and 0.5% NaOH solution tends to make the rock surface preferentially oil-wet.

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