Engineering Journal of the University of Qatar, Vol. 11, 1998, p. 49 - 64

EFFECT OF DRILLING FLUIDS CONTAMINATIONS ON SAUDI RESERVOIR ROCK WETTABILITY

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ABSTRACT

Wettability is a key parameter that affects the petrophysical properties of reservoir rocks. Mud filtrate during drilling pay zone causes a significant change in rock wettability that will affect the oil production and enhanced oil recovery. This change depends on the mud filtrate and the oil rock systems studied. The objective of this paper is to investigate the influence of water base mud, oil base mud, and Partially Hydroxide Polyacrylamide (PHPA) mud filtrate on the reservoir rocks wettability. The drilling fluid compositions that recommended for drilling horizontal wells had been used in this study. The reservoir rocks used were Saudi water-wet sandstone and limestone. The contact angle was used to measure the rock wettability. Also, the effect of temperature on wettability alteration had been studied

The results showed that the rock samples used are originally water-wet. Water-based drilling fluids tends to make the system water wet. The contact angle tends to increase with increasing NaOH and KOH additives as well as temperature increase. In contrary, oil-based drilling fluid changes the system from water wet to strongly oil-wet. This change is higher in the case of using crude oil than diesel oil. The PHPA mud contamination strengthens the wettability of water-wet reservoir rocks towards water. The increase of temperature increases the contact angle in the case of using water-based mud and oil-based mud and vice versa for the case of PAPA muds. The same results have been detected with limestone samples with high slight difference in the contact angle. The contact angle tends to reach its original values after cleaning in case of using limestone.

INTRODUCTION

Wettability of reservoir rock surface is defined as the tendency of one fluid to spread over or adhere to a solid surface in the presence of other immiscible fluids. In the reservoir, this relates to the preference the rock surface has for either oil or water. For a water-wet rock, water occupies the small pores and contacts the majority of the rock surface by a thin film. Similarly. In an oil-wet system, the rock surface is preferentially in contact with the oil [1].

Wetability is the major factor controlling the relative permeability effects. The effective oil permeability can effectively be reduced if the wettability of the rock surface is altered from water-wet to oil-wet [1]. It also is the major factor controlling the distribution of fluids in the reservoir and an important factor in the performance of waterfloods [2]. It affects the oil recovery for the primary, secondary and enhanced oil recovery (EOR) as well as gas injection [2-7]. It is considered as one of the principle parameters influencing saturation distribution, and fluid flow in porous medium [5].

When drilling the producing interval or cutting a core, drilling mud filtrate and colloidal particles of drilling mud invade the formation adjacent to the wellbore. Any alteration to the virgin reservoir rock wettability, intrinsic permeability, water saturation and oil viscosity can be detrimental to the reservoir productivity. Furthermore, altered reservoir rock wettability can give misleading results in core analyses to be used in a reservoir flow simulator [1].

Three major types of drilling fluids are recommended to drill oil and gas horizontal wells. These are water-base mud, oil-based mud, and PHPA mud. Oil based mud is used to drill oil wells because it is inexpensive and easy to prepare. It a less effects on the environment. Low toxicity water-base mud is nowadays-used world wide to protect the environment. Oil-based drilling muds are often used to drill cores for reservoir evaluation as well as drilling the pay zone. PHPA mud is nowadays recommended to drill oil and gas wells because of environmental regulations and shale stability [8-12]. An induced wettability change can alter the productivity of the producing well [1,5,6].

Research conducted in this field was devoted to study the effect of drilling components separately on the reservoir rock wettability [13-16]. The authors concluded that the results depend on the change on the component as well as the rock type. Mixing the components together brings results different than single component separately. Therefore, wettability experiments should be conducted to find out the effect of mixing mud components together on reservoir rock samples [13-16].

In these work six compositions of water-based mud, two compositions of oil-based mud and one compositions of PHPA mud have been tested. The effect of contamination of these compositions on Saudi sandstone and limestone samples has been evaluated. Also, the effect of temperature on wettability change has been determined. Contact angle method was used to determine the rock wettability because of its accuracy with oil/brine/rock systems.

EXPERIMENTAL WORK

Samples 2.5 inch (3.81 cm) in diameter and 1.0 inch (2.54 cm) long with a very smoothed surface were used to measure the contact angle. The cores were obtained from wells drilled in Aramco production area in the Eastern province of the kingdom of Saudi Arabia. The procedures of cleaning reservoir core samples presented by Cuiec [17] were used in this study. The composition of sandstone and the limestone cores were determined using x-ray analysis. The sandstone cores consist essentially of quartz (>70%). The clay content in the cores is in the range from 10 to 15%. The associated non-clay minerals are mainly feldspar and pyrite. The limestone cores consist of calcite and gibsite (>70%). This sample also has clay content of about 20%. The limestone cores also contain non-clay minerals, which are mainly feldspar, pyrite, talc and iron oxides. After the samples have been cleaned, they were dried under controlled humidity. The samples were then saturated with 3.5% NaCl brine and the contact angle was measured. The same samples were contaminated with mud by displacing brine water with mud. The compositions of the mud compositions used were chosen from recommended manuals of specialized service companies [8,9,18,19]. These compositions are given in Table 1&2. The rheological properties of the drilling fluids used were measured using Fann V.G meter. The filtration and the pH value were measured using American Petroleum Institute (API) filter press and an analytical pH meter. Safaniya crude oil was used to measure the contact angle. The oil is acidic and has 1.4 acid number and 0.68 specific gravity.

The wettability measurements were made using the contact angle method [1] where the contact angle between crude oil and an aqueous solution was measured. Figure 1 shows a schematic diagram of the apparatus solution. The aqueous solution used was brine 3.5% NaCl concentration. The sample was immersed and leveled in the aqueous solution. An oil droplet was put in contact with the downward surface of the core sample while it was immersed in the aqueous solution. A camera was used to take pictures of the oil droplet. The oil droplet was photographed at different time intervals on a period of 24 hours to investigate the change of contact angle with time. The stabilized contact angle was taken to evaluate the reservoir rock wettability. The measurements were carried out at temperatures of 25 and 60 C to evaluate the effect of temperature change of the contact angle as well as the reservoir rock wettability. The measured contact angle in the aqueous phase was determined by making a tangent to both sides of oil droplet to decrease the absolute error. The error in this case was within ±1 .

Table 1. Composition of Water Base-Muds

Material	WBM1	WBM2	WBM3	WBM4	WBM5	WBM6
Water, cc	1000	1000	1000	1000	1000	1000
KOH, gm	3	0	3	0	0	0
KC, gm	15	0	15	0	0	0
CMC, gm	2.5	2.5	2.5	2.0	0	0
NaOH, gm	0	0.65	0	2.0	5.0	0
Bent., gm	30	20	10	20	0	0
Zeogel,gm	0	0	50	0	65	65

Table 2. Composition of Oil Base-Muds and PHPA Mud

Material	Diesel Oil Mud	Crude Oil Mud	PHPA Mud
Water/oil ratio	15/85	15/85	100/0
Invermol, cc	26.6	26.6	0
EZ-Mul, cc	3.9	3.9	0
Duratone, gm	35.3	35.3	0
Geletone, gm	24.7	24.7	0
Lime, gm	15.0	15.0	0
Oil volume, cc	1000.0	1000.0	0
Water volume, cc	184.2	184.2	1000.0
Barite, gm	484.0	484.0	0
NaCl, gm	16.1	16.1	0
PHPA, gm	0	0	3.0
*Tackle, gm	0	0	0.4
Caustic Soda, gm	0	0	2.0
Bentonite, gm	0	0	15.0

* Tackle = trade name of a thinner.

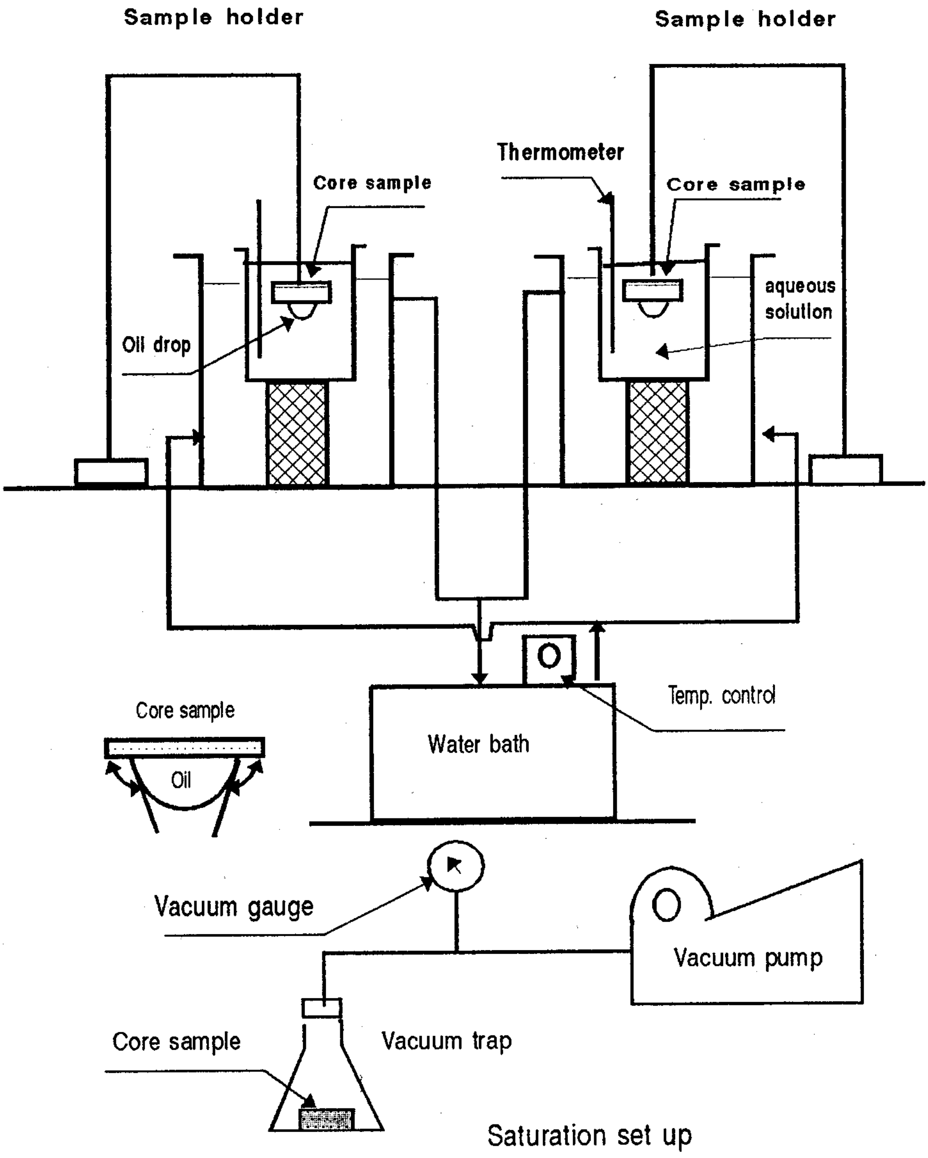

Fig. 1. Contact angle measurement apparatus

RESULTS AND DISCUSSION

To investigate the effect of drilling fluids contamination on reservoir rocks wettability, sandstone and limestone samples along with six compositions of water-based mud, diesel oil-based mud, crude oil-based mud and PHPA mud were used for measuring the contact angles at 25 C and 60 C. The compositions of these drilling fluids are shown in Table 1&2. The amount of water-based mud components had been changed to determine the effect of component change on the rock sample wettability. The properties of all muds are given in Table 3. All measurements were conducted at the same conditions.

Effect of Water-Based Muds

To determine the effect of water-based mud contamination on Saudi reservoir wettability, six compositions were used, Table 1. Four of them were prepared using bentonite and two were prepared using zeogel (attapulgite). The other additives were Sodium Hydroxide (NaOH), Potassium Chloride (KCl) and Potassium Hydroxide (KOH), Carboxymethylcellulose, and Q-broxin. The rheological properties, Table 3 show that the muds have low viscosity, yield value and gel strength. The fluids are alkaline with high pH value. The bentonite mud gave normal filtration rate while the attapulgite muds gave high filtration rate.

Concerning the contact angle measurements, the contaminated samples were stored for 5 days as a minimum time for mud to contact the reservoir rock during drilling and completion. Figures 2&3 show the variation of contact angle with respect to different water-based drilling fluids using sandstone and limestone samples at different temperature. Figure 2 shows that the presence of NaOH in the drilling fluids WBM2, WBM4, and WBM5. Drilling fluids prepared without NaOH WBM1, WBM3, and WBM6 bring contact angle more or less similar to brine. This is due to the absence of NaOH in the mud. The presence of bentonite and NaOH increases the contact angle for WBM2&WBM4. This increase is high at low concentration of NaOH with bentonite, WBM2. This can be attributed to the low pH value of the composition. This low pH value resulted from adding bentonite and NaOH which reduced the alkalinity of the drilling fluids [20]. This reduction in alkalinity enhances the increase of contact angle. Adding Zeogel to the drilling fluids, WBM3, WBM5&WBM6, does not affect the contact angle. However, the presence of NaOH with Q-brogan, WBM5, slightly increases the contact angle.

The presence of KOH in mud, WBM1 and WBM3, decreases the contact angles. This shows that the effect of NaOH on the contact angle is higher than the effect of KOH. This could be attributed to the equivalency of the mineral.

Table 3. Properties of Water Base-Muds, Oil Base-Muds, and PHPA Mud

Property	WBM1	WBM2	WBM3	WBM4	WBM5	WBM6	OBM1	OBM2	PHPA
Density, ppg	8.91	8.71	8.43	8.62	8.75	8.72	9.81	10.4	8.7
μp, cp.	2.98	2.98	1.11	2.25	0.99	1.06	26.0	104.0	26.5
μa, cp.	1.50	1.00	1.75	2.25	1.99	1.78	39.6	132.0	19.5
Yp, lb/100^2	1.21	1.11	2.23	1.74	2.00	1.44	27.0	56.0	10.5
*Gel lb/100^2	1.47	1.96	2.38	1.89	0.80	1.00	13.0	26.0	6.0
PH value	11.50	10.50	12.00	11.50	12.18	11.95	7.89	8.38	7.8
Filteration, cc/30 min	24.50	15.50	34.50	15.50	206.0	22.00	1.45	1.50	140.0

* Gel strength measured after 10 minutes.

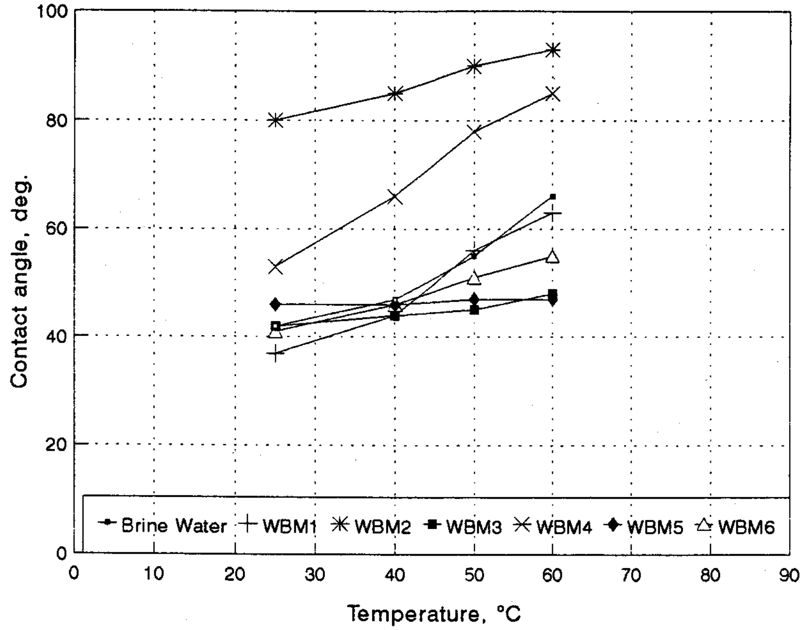

Fig. 2. Effect of water base mud and temperature on contact of sandstone rock

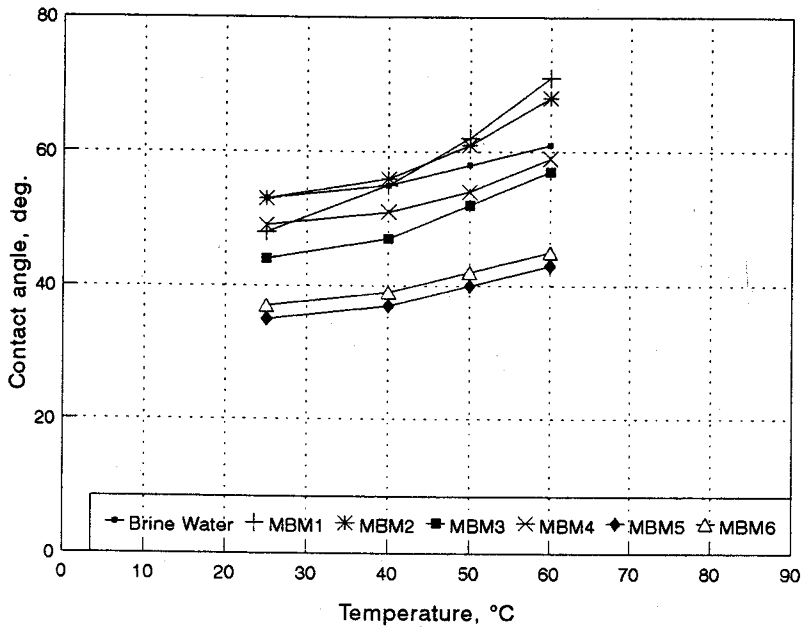

Fig. 3. Effect of water base mud and temperature on contact angle of limestone rock

Measuring the contact angle at 60°C shows that the temperature increase brings contact angle higher than that at 25°C in all cases. This means that the temperature increase enhances the wettability of water-based mud contaminated rocks towards water-wet [15,20].

Figure 3 presents the results of the same experiments conducted for Saudi limestone samples. The results show that the contact angle variations are similar to that obtained with sandstone samples. However, the contact angle in this case is lower than that for sandstone samples. Also, increasing the temperature increases the contact angle. Moreover, the contact angle values are in the range of water-wet reservoirs.

Effect of Oil-Based Drilling Fluids

To investigate the effect of oil-based mud contamination on reservoir rock wettability, two types of oil-based muds were used, as shown in Table 2. The first one had diesel as a continuous phase and the second one had crude oil. The main components in the oil based-mud were emulsifier (Invermul), hydrophilic clay (Geletone), oil dispersible colloid (Duratone), fluid loss control and dispersant (EZ-Mul), lime, and barite. The water/oil ratio used was 15/85, which is common in oil field applications. The selection is aimed to differentiate between diesel-oil and crude-oil muds. The rheological properties (viscosity, yield point and gel strength) of these muds were tested and are listed in Table 3. The results show that crude oil-based mud possesses viscosity, yield point and gel strength higher than those of diesel oil-based mud. This is because crude oil is more viscous than diesel and contains more components including diesel itself.

Concerning the contact angle measurements, the contaminated samples were stored for 5 days as a minimum time for mud to contact reservoir rock during drilling or completion. The results are shown in Figures 4 and 5. Figure 4 gives the contact angle for sandstone samples while Figure 5 is for limestone samples. The contact angle was measured for brine, diesel oil mud, and crude oil mud at different temperature.

Figure 1 shows that the sandstone samples saturated with brine attained an average contact angle of 38 . This angle lies in the range of water-wet reservoir [2]. Contaminating the samples with diesel oil mud increased the contact angle to about 128 , oil-wet range [2]. This means that the sandstone samples were changed from water-wet to oil-wet. This could be attributed to the chemicals used to prepare the mud which include emulsifiers, surfactants and wetting agent. Contaminating the samples with crude oil mud attained a higher contact angle than diesel oil mud, about 150 , and produced highly oil-wet samples. This could be attributed to the composition of the crude oil which contain

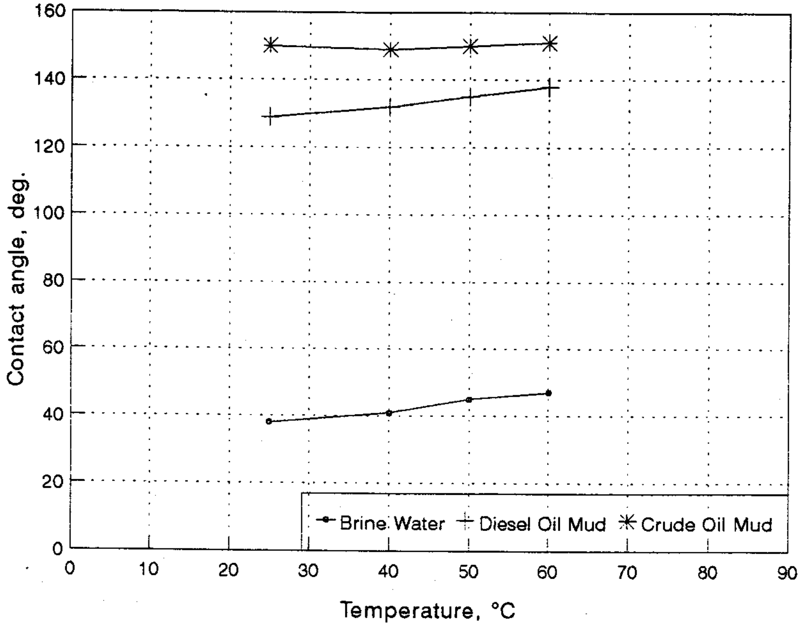

Fig. 4. Effect of oil base mud and temperature on contact of sandstone rock

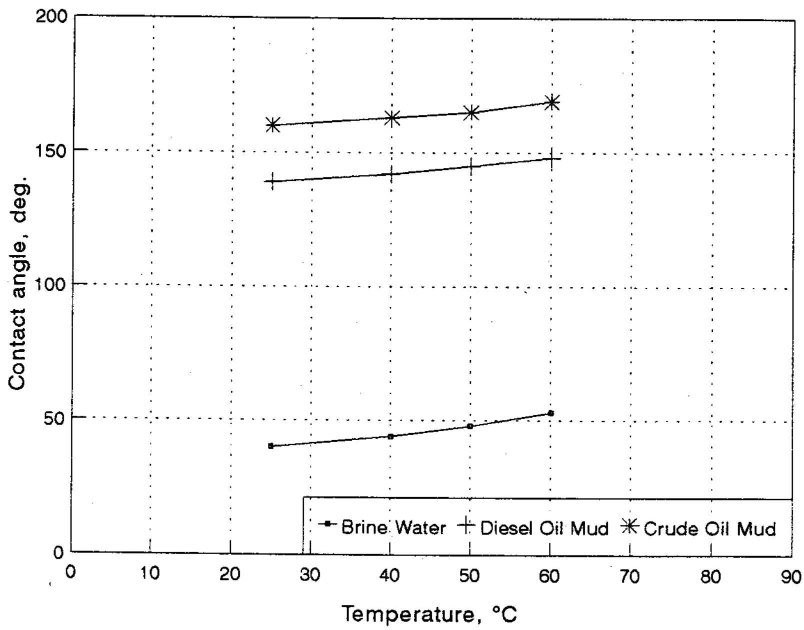

Fig. 5. Effect of oil base mud and temperature on contact angle of limestone rock

diesel and other components. Also, increasing the temperature raised the contact angle and brought the sample towards oil-wet [16].

Figure 5 gives the results of the contact angle measurements for limestone samples at the same conditions of the sandstone samples. The contact angle in this case is higher than in the case of sandstone samples under the same conditions. This can be attributed to a certain chemical reaction that occurred between oil-based mud components and the limestone samples that yielded strongly oil-wet samples.

Effect of PHPA Drilling Fluid

To investigate the effect of PHPA mud contamination on reservoir rock wettability, the composition recommended by the service companies was used, Table 2. The mud is composed of water, PHPA polymer, Tackle (thinner), bentonite, and caustic soda. This composition is considered as environmentally clean and shale stable mud. The rheological properties of this mud were tested and are listed in Table 3. The results show that the mud has an intermediate plastic viscosity and normal yield strength and gel strength. The API filtration rate is higher than that of water-based and oil-based muds, which means that it will invade the reservoir rock.

Concerning the contact angle measurements, the contaminated samples were stored for 5 days as a minimum time for mud to contact reservoir rock during drilling or completion. The results are shown in Figures 6 and 7. Figure 6 gives the contact angle for sandstone samples at different temperatures while Figure 7 is for limestone samples. The contact angle was measured first for noncontaminated samples and next for the same samples contaminated with PHPA mud filtrate. The measurements were conducted at the same temperatures.

Figure 6 shows that the sandstone samples saturated with brine attained an average contact angle of 52 . This angle lies in the range of water-wet reservoir [1]. Contaminating the samples with PHPA mud decreased the contact angle to about 34 at room temperature which means that the wettability to water is increased [1]. This means that the PHPA mud contamination increases the reservoir rock wettability towards water. This could be attributed to the PHPA polymer adsorption on the grains. This adsorption increases the affinity of the grains to water and increases the hydrophilic properties of the rock.

Figure 6 also shows the effect of temperature increase on the contact angle for both brine saturated and PHPA saturated sandstone samples. It shows that increasing the temperature reduces the contact angle between oil and rock sample. This means that

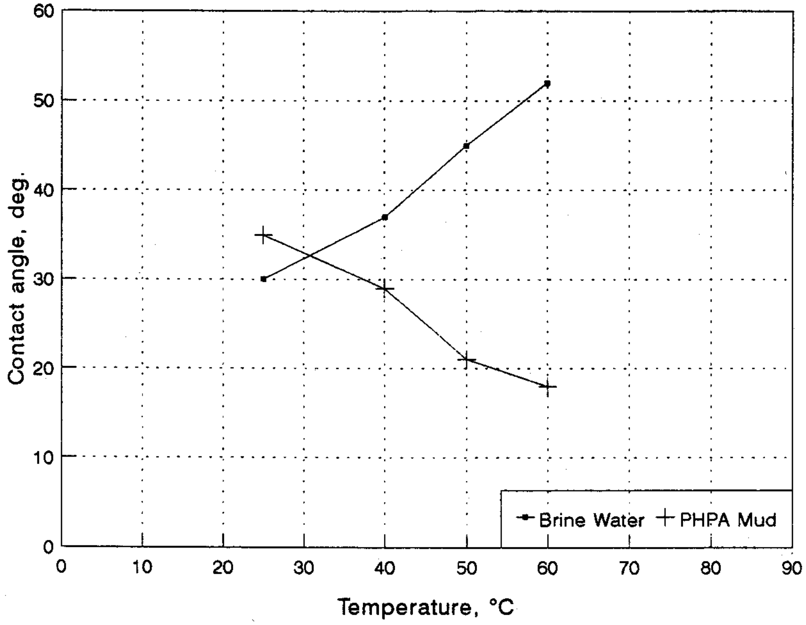

Fig. 6. Effect of PHPA mud and temperature on contact angle of sandstone rock

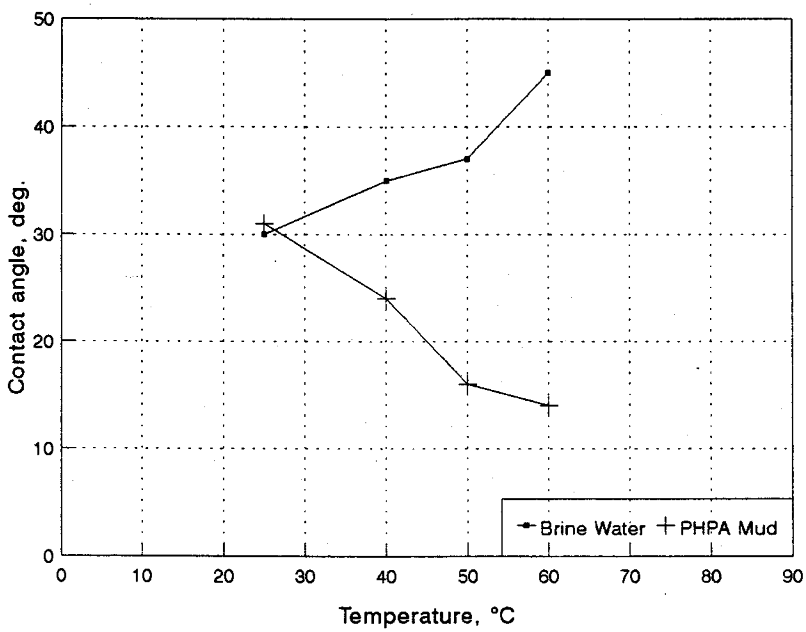

Fig. 7. Effect of PHPA mud and temperature on contact angle of limestone rock

temperature increase increases the sandstone rock sample wettability towards water, i.e. the sample becomes more water-wet.

Figure 7 gives the results of the contact angle measurements for limestone samples under the same conditions of the sandstone samples. The contact angle in this case is lower than in the case of sandstone samples under the same conditions. This can be attributed to the composition of the limestone samples, which contains certain amount of clay and the adherence of the polymer to the surface of the grain. This adherence resulted in lower contact angle that yields strongly water-wet samples. Also, the temperature increase changes the limestone rock samples to strongly water-wet.

CONCLUSIONS

Based on the experimental results obtained in this study, the following conclusions are reached:

1. The Saudi reservoir samples used in this study are originally water-wet.

2. Water base muds change the change the contact angle in the range of water wet reservoirs. Increasing the temperature reduced the contact angle slightly.

3. Adding NaOH brings a slight increase in contact angle.

4. Oil-Base filtrate changes the water-wet reservoirs to strongly oil-wet due to presence of emulsifying agents, surfactants and wetting agents used in preparing the mud.

5. PHPA mud recommended for environmentally clean drilling yields moderate viscosity, yield point , gel strength and high filtration rate.

6. Contaminating the samples with PHPA mud filtrate increases their wettability to strongly water-wet.

7. Increasing the reservoir temperature decreases the contact angle for both water-base muds and PHPA mud and decreases it with oil-base mud.

8. The same results are for both sandstone and limestone samples with slight difference in the measured values.

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