Alteration of Saudi Reservoir Rocks Wettability Due to Drilling Fluids Contamination

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Abstract. Wettability is a key parameter that affects the petrophysical properties of reservoir rocks. Mud filtrate during the drilling of the pay zone causes a significant change in rock wettability that will affect the oil production and enhanced oil recovery methods [EOR]. This change depends on the mud filtrate and the oil rock systems involved. 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 formulations 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 tend to make the system water-wet. The contact angle tends to increase with increasing NaOH and KOH additives at both 25° and 60°C. In contrast, oil-based drilling fluids change the system from water-wet to strongly oil-wet. This change is higher with crude oil than with diesel oil. PHPA mud contamination strengthen the wettability of water-wet reservoir rocks towards water. The effect of temperature increase is variable. It increases the contact angle with oil-based mud while reduces it with water-based and PAPA muds. This change is higher with limestone rock than with sandstone rock.

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].

Wettability 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]. Wettability affects the oil recovery for the primary, secondary and enhanced oil recovery (EOR) as well as gas injection [2-8]. It is considered as one of the principle parameters influencing saturation distribution and fluid flow in porous medium [5].

Many different methods have been proposed for measuring the wettability of a system. They include quantitative methods-contact angle, imbibition and forced displacement (Amott) method, and U.S. Bureau of Mines (USBM) method-and qualitative methods-imbibition rates, microscope examination, floatation, glass slide method, relative permeability curves, permeability/saturation relationship, capillary pressure curves, capillarimetric method, displacement capillary pressure, reservoir logs, and dye adsorption [6].

Although, no single method exists, the three quantitative methods generally are used. The contact angle measures the wettability of a specific surface, while the Amott and USBM methods measure the average wettability of a core. The contact angle measures the wettability of crude and brine on a polished surface. It is used to examine the effects on wettability of experimental conditions, such as pressure, temperature, and brine chemistry. The USBM and Amott methods measure the average wettability of cores. They are superior to the contact angle method when the wettability of native- or restored-state core is measured [6].

Some fluids used for drilling, coring, completion, and workover damage the reservoir rock properties in the near hole vicinity because of the creation of an emulsion, the hydration of clays, the migration of fines from the formation, the precipitation of salts, the modification of wettability, etc. [9]. Likewise, solids present in such fluids may penetrate into the porous medium and reduce flow possibilities. The productivity of production wells may be affected for one or several of these reasons [9].

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. Water-based mud is used to drill oil wells because it is inexpensive and easy to prepare. It has a less effects on the environment. Low toxicity water-base mud is nowadays-used world wide to 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 [8-14]. An induced wettability change due to mud filtrate can alter the productivity of the producing well [1,5,7].

Research conducted in this field was devoted to the effect of drilling components separately on the reservoir rock wettability [15-20]. Sharma and Wunderlich [19] reported that water base drilling fluid components which have been considered to be bland can in fact alter wettability. Carboxymethyle cellulose (CMC), dextride, starch, drespac, Hydroxyethyl cellulose (HEC) and xanthan gum have all been found to make oil-wet surfaces less strongly oil-wet while little effect was observed on water-wet surfaces. Van et al. [18] tested the oil base mud components and found that most oil base mud components, especially surfactants, greatly change the wettability of Berea sandstone samples from a strongly water-wet condition to various degrees of oil wetness. Ballard and Dawe [21] tested wettability alteration caused by oil base mud filtrate using a glass micromodel, which is a two dimensional pore networks etched in glass. They found that oil base mud filtrate causes the surface of the glass to become more oil-wet, even at low filtrate and surfactant concentrations. From these one can conclude that changes by changing the component as well as the rock type. Mixing the components together caused results different than single component separately. They also recommended performing wettability tests when the formation composition changes [15-20].

Six formulations of water-based mud, two formulations of oil-based mud and one formulation of PHPA mud have been tested in this work. The effect of the filtration of these formulations on Saudi sandstone and limestone reservoir rock samples has been studied. Also, the effect of temperature on wettability change has been determined. Contact angle method was used to determine the rock wettability.

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. A mill machine has been used to smooth the surface of samples because rock roughness affects the contact angle measurement [2]. 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 [20] 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 sample also contains non-clay minerals, which are mainly feldspar, pyrite, talc and iron oxides. Dahab *et al.* [22] in their study about the effect of clay content on reservoir rock wettability reported that the presence of chloride and a higher percentage of clay increase the contact angle. The clay content in this sample remains constant and their effect can not be considered as a main factor. 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 formulations used were chosen from recommended manuals of specialized service companies [10,11,22,23]. These compositions are given in Tables 1 and 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 an acid number of 1.4mg KOH/g crude oil 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 used. 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 angle was taken to evaluate the reservoir rock wettability. The measurements were carried out at temperatures of 25°C 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°.

Results and Discussion

To investigate the effect of drilling fluids contamination on reservoir rocks wettability, sandstone and limestone samples along with six formulations 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 formulations of these drilling fluids are shown in Tables 1 and 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.

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	3
KCl, 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

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.	1.5	1.0	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	11.5	10.5	12.0	11.5	12.18	11.95	7.89	8.38	7.8
Fileration, cc/30 min	24.5	15.5	34.5	15.5	206.0	22.00	1.45	1.50	140.0

Tackle = trade name of a thinner.
Gel strength measured after 10 minutes.

(a) Effect of water-based muds

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

Concerning the contact angle measurements (as shown in Fig. 1), 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 and 3 show the variation of contact angle with respect to different water-based drilling fluids using sandstone and limestone, reservoir rock samples at 25° C and 60°C. Figure 2 shows that the presence of NaOH in the drilling fluids-WBM2, WBM4, and WBM5-increases the contact angle reference to brine sample in the range of water wet reservoirs. Drilling fluids prepared without KOH-WBM1, WBM3, and WBM6-bring contact angle more or less similar to brine. This is duc to the absence of NaOH in the mud. The presence of bentonite and NaOH increases the contact angle for WBM2 and 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 means that this concentration of bentonite and NaOH reduces the alkalinity of the drilling fluid [25]. This reduction in alkalinity enhances the increase of contact angle. Adding Zeogel to the drilling fluids-WBM3, WBM5 and WBM6-docs not affect the contact angle. However, the presence of NaOH with Q-broxine, WBM5, slightly increases the contact angle.

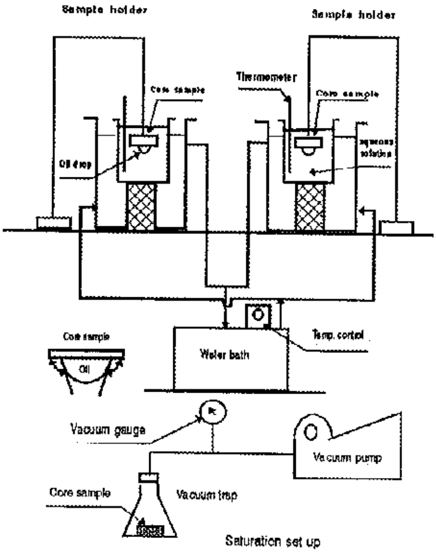

Fig. 1. Contact angle measurement apparatus.

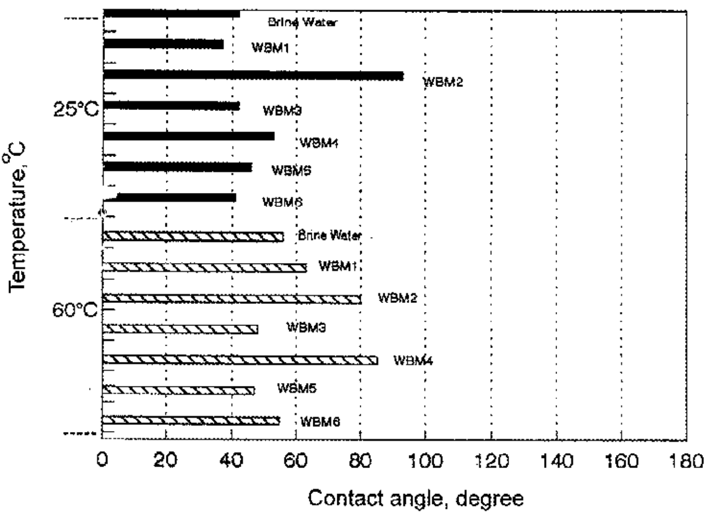

Fig. 2. Effect of WBM type and temperature on contact angle for sandstone rock samples.

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 in the chemical compound [16].

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 intermediate-wet [17,25].

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

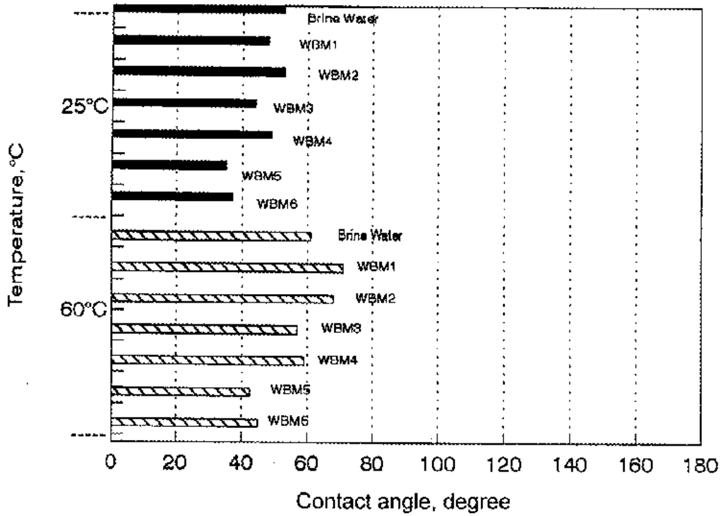

Fig. 3. Effect of WBM type temperature on contact angle for limestone rock samples.

(b) 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, 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 of these muds were tested and are listed in Table 3. The results show that crude oil-based mud has rheological properties higher than 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 Figs. 4 and 5. Figure 4 gives the contact angle for sandstone samples while Fig. 5 is for limestone samples. The contact angle was measured for brine, diesel oil mud, and crude oil mud at 25 °C and 60 °C.

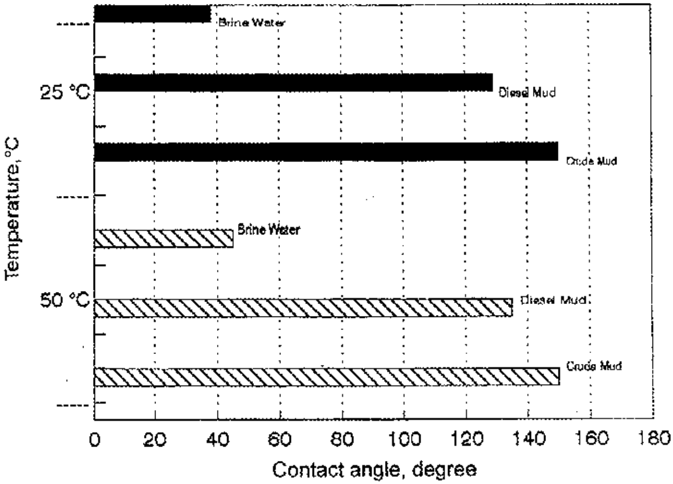

Fig. 4. Effect of OBM type temperature on contact angle for standard rock samples.

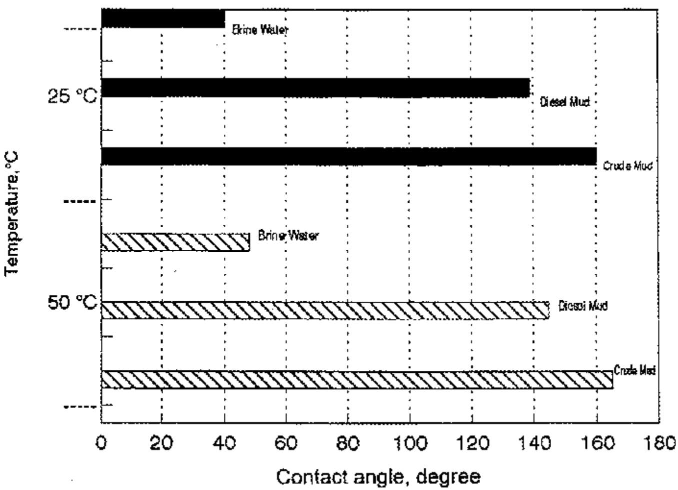

Fig. 5. Effect of OBM type temperature on contact angle for limestone rock samples.

Figure 4 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 [16]. 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 crudeoil, which contain diesel and other components. Also, increasing the temperature raised the contact angle and brought the sample towards oil-wet.

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 at all conditions. This can be attributed to a certain chemical reaction that occurred between oil-based mud components and the limestone samples, which yielded strongly oil-wet samples.

(b) 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 high 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 Figs. 6 and 7. Figure 6 gives the contact angle for sandstone samples at different temperatures while Fig. 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.

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 [2]. 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 [2]. 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.

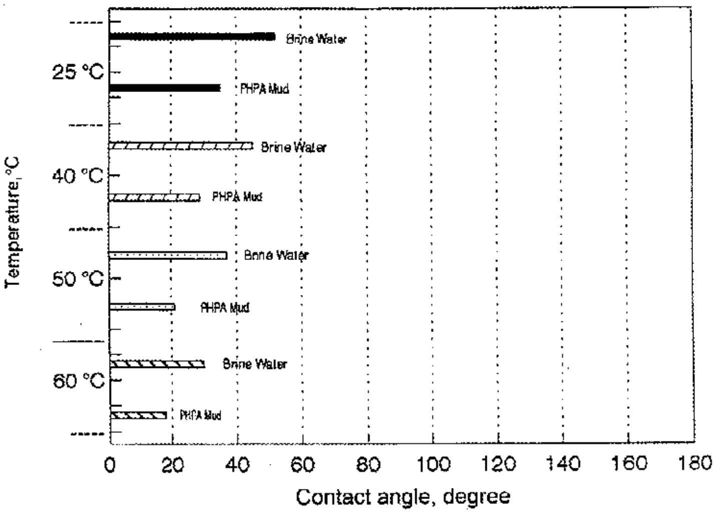

Fig. 6. Effect of PHPA mud and temperature on contact angle for limestone rock samples.

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 temperature increase brings 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 at the same conditions of the sandstone samples. The contact angle in this case is lower than in the case of sandstone samples at all conditions. This can be attributed to the composition of the limestone samples and its relationship with the mud composition, which yields strongly water-wet samples. Also, the temperature increase changes the limestone rock samples to strongly water-wet.

From the previous results and discussion it can be seen that the water base mud and PHPA mud keep the rock water wet or change the wettability towards intermediate-wet due to the chemical components used in formulating these muds [2]. The oil base mud changes the reservoir rock wettability from water-wet to strongly oil-wet due to the existence of surfactants and wetting agents. This change in wettability is due to the adsorption of some chemicals and/or minerals on the rock surface as well as the grain surface [15,16]. This adsorption changes the characteristics of the surface area of the grains and the rock. To restore the original wettability of the rock, the sample should be flushed with a certain solvent suitable to clean the surface. Otherwise this alteration holds for a long period of time and will affect the productivity as well as the injectivity of the reservoir [19].

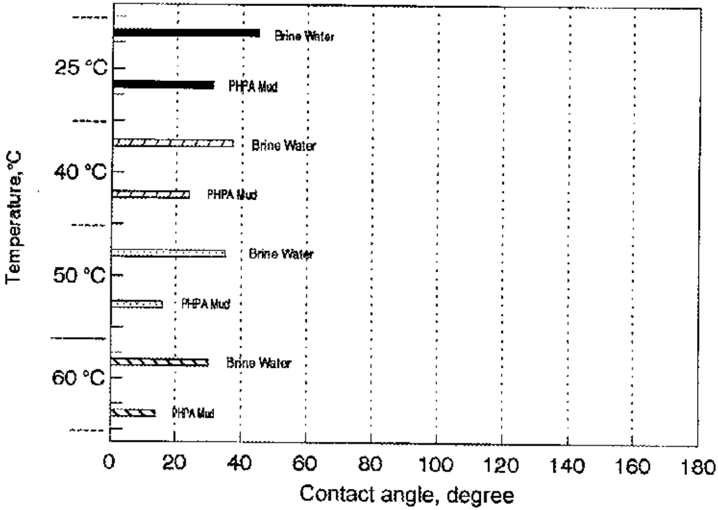

Fig. 7. Effect of PHPA mud and temperature on contact angle for limestone rock samples.

Conclusions

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

1. The Saudi reservoir rock samples used in this study are originally water-wet. They have 10-15% clay content.

2. Water base muds 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 emulsifying agents, surfactants and wetting agents used in preparing the mud.

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

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

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

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تغير خاصية تبلل صخور المكامن السعودية نتيجة التلوث بسوائل الحفر

عبدالعليم هاشم السيد ، مساعد ناصر العواد و محمد عبدالرحيم الصديقي

قسم هندسة النفط ، كلية الهندسة ، جامعة الملك سعود ، ص.ب ٨٠٠ ،
الرياض ١١٤٢١ ، المملكة العربية السعودية

(استلم في ٢٢/١٠/ ١٩٩٧ م ، وقبل للنشر في ٣٠/٥/ ١٩٩٨ م)

ملخص البحث. تعتبر خاصية التبلل عامل أساسي يؤثر على الخواص البتروفيزيقية لصخور المكامن ، فترشيح الطينة أثناء حفر الطبقة المنتجة يحدث تغييرًا جوهريًا لخاصية تبلل الصخر والتي بدورها تؤثر على إنتاجية الزيت وطرق الإنتاج المحفّز للنفط. فهذا التغيير يعتمد على ترشيح الطين ، نظم الزيت والصخر المأخوذة في الاعتبار. إن الغرض من هذه الورقة هو توضيح تأثير كل من الطينة مائية القاعدة ، الطينة زيتية القاعدة والطينة المجهزة من البولي أكريلاميد المؤكسدة جزئيًا على خاصية تبلل صخور المكامن. أستخدم في هذه الدراسة تكوينات سوائل الحفر الموصى بها في حفر الآبار الأفقية ، والصخور المستخدمة هي صخور الحجر الجيري والحجر الرملي السعودي مائية التبلل. استخدمت طريقة زاوية التلامس لقياس خاصية تبلل الصخر ودراسة تأثير درجة الحرارة على تغير خاصية التبلل .

أظهرت النتائج أن صخور المكامن السعودية المستخدمة هي في الأساس مائية التبلل ، وأن سوائل الحفر مائية التبلل تميل إلى جعل النظام مائي التبلل بدرجة أكبر، وزاوية التلامس تميل إلى الزيادة مع إضافة كل من هيدروكسيد الصوديوم وهيدروكسيد الكالسيوم عند درجتي حرارة ٢٥ و٦٠ درجه مئوية . على العكس من ذلك فإن سوائل الحفر زيتية التبلل تغير النظام إلى زيتي تبلل قوى ، هذا التغير في حالة استخدام الزيت الخام أكبر منه في حالة استخدام زيت الديزل. التلوث بسائل الحفر من البولي أكريلاميد المؤكسد جزئيًا يقوّي الصخور مائية التبلل في اتجاه الماء كما أن تأثير درجة الحرارة متغير، فهي تزيد درجة التلامس مع سائل الحفر زيتي القاعدة وتقللها مع سائل الحفر مائي القاعدة ، وسائل الحفر المعد من البولي أكريلاميد المؤكسد جزئيًا ، هذا التغير في حالة صخور الحجر الجيري أكبر منه في حالة صخور الحجر الرملي.