ALTERATION OF WETTABILITY BY DRILLING MUD FILTRATES

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Abstract

Reservoir core samples are usually exposed to some kind of drilling fluid filtrate during coring, recovery, shipping, and storage. Choice of drilling fluid is generally dominated by operating conditions, rather than by wettability preservation concerns. If useful laboratory measurements of oil displacement behavior are to be made on core samples in their recovered state (so-called fresh cores), knowledge of possible alterations in wettability due to the drilling fluid is required.

Individual components of drilling muds and filtrates prepared from whole muds were investigated. Solutions of individual components were flushed through strongly water-wet (untreated) Berea sandstone cores. Changes in wettability were assessed by measurement of Amott indexes for brine and refined oil. In the study of mud filtrates, suites of treated Berea sandstone cores were prepared with a wide range of initial wetting conditions. Amott indexes were compared before and after cores were flushed with the filtrates.

In general, the effect of the drilling fluid components on the wettability of strongly water-wet (untreated) cores is overestimated by examining them individually. It appears that surface-active components adsorb on clays and are removed from the filtrate by formation of the mud cake. Results of this study point to practical drilling mud formulations that cause only minor changes in wetting over a wide range of initial wetting conditions.

Introduction

There is long-standing concern that components of drilling muds can alter the wettability of portions of the formation with which they come in contact.[1-4] Wettability alteration is particularly severe for oil-based fluids because of the oil-wetting surfactants commonly used. The only oil-based drilling fluid ever recommended for use when preservation of wettability is a goal of the coring program is unoxidized reservoir crude.[3,4] This option is seldom chosen because of safety concerns. The possibility that exposure to air will make even the reservoir crude a wettability altering fluid may also be a problem.

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Table 1 summarizes the varying conditions under which the effects of drilling fluids, their filtrates, or individual components have been reported and the different methods used to characterize wetting in each case (including the present work).

Table 1. Wettability tests of drilling muds and their components.

		Drilling Fluid						Core Wettability (initial)					Measurements						
		Water-based			Oil-based			Water-wet[1]		Oil-wet									
References (1st author and year)	#	Whole mud	Filtrate	Components	Whole mud	Filtrate	Components	Sandstone	Limestone	Reservoir[2]	Chemical	Crude oil	Amott	USBM	Imbibition,other	Relative perms	Contact angles	Zeta potential	Visual
Bobek (1958)	2			x				ss/f	ls			4			x				
Amott (1959)	1		x			x		B/f		C/p			x						
Burkhardt (1958)	15		x							T/r					x				
Thomas (1984)	6					x		B/u								x			
Sharma (1985)	16			x				B/f				5	x	x			x		
Wendel (1985)	7					x		B/u		H/r				x					
Ballard (1988)	8					x		Gl											x
Yan (1988)	9				x		x	B/u			3	5	x	x		x	x		
Menezes (1989)	10						x	Q,Si									x	x	
Cuiec (1989)	11	x			x			F,V/u	R			6	x			x			
Wunderlich (1990)	12				x			B/f				5			x				
Jia (1994)			x	x				B/u				7	x						

1 B=Berea or Ohio F=Fontainebleau Gl=glass Q=quartz R=Rouffach Si=silica flour V=Vosges ls= various limestones ss=various sand stones / f=fired u=unfired

2 C=California T=East Texas H=Hutton (North Sea) / p=preserved (fresh) r=restored

3 sandstone core treated with Quilon-C

4 Weiler sandstone core treated for 1 day with Elk Basin crude oil, $S_o=1$

5 asphaltenes precipitated from crude oil ($S_o=1$) with n-pentane in sandstone core

6 cores aged in crude oil from southern France for 10 days at 80°C at S_{wi}

7 cores aged in Moutray or asphalt at temperatures up to 95°C at S_{wi}

The results of studies related to the effect of drilling muds on wettability are summarized in Table 2. The most restrictive formulations for a water-based drilling fluid designed to preserve core wettability permit only inorganic salts.[7,12] Rarely would such a drilling fluid be practical, however. Ehrlich, *et al.*[14] used a water-based drilling fluid with $CaCO_3$ as the sole additive. Bobek, *et al.*[2] examined selected components of water-based muds and found that starch, pyrophosphate, and lignosulfonate made water-wet samples somewhat less water-wet, while lime and carboxymethylcellulose (CMC) made a sample of neutral wettability more water-wet. Less change was reported for restored-state reservoir cores exposed to water-based filtrate, rather than individual components.[15] Sharma and Wunderlich[16] also examined many of the components of typical water-based drilling fluids and found that most of them did not alter the wetting of strongly water-wet rock, but nearly all made mixed-wet samples more water-wet. The only component, other than inorganic salts, that did not increase water-wetness was bentonite. Lignosulfonate was found to increase water-wetness of the mixed-wet samples and to decrease water-wetting of strongly water-wet samples.

The impact on wettability of the more usual components of oil-based muds have been reported in a number of studies.[1,6-13] Base oils and barite, used to increase mud weight, may leave wetting unchanged, but nearly everything else alters wetting of both water-wet and mixed-wet cores.

As shown in Table 2, there is general agreement regarding the effects of oil- and water-based muds on wetting, but there are some discrepancies that may relate either to different initial conditions or to variations in the techniques used to assess wetting. The present study focuses on the wettability altering properties of water-based muds. A series of cores were prepared, which provided a wide range of initial wetting conditions. Filtrates of practical mud compositions were tested over the full range of initial wetting conditions. In addition, water-based mud components were tested in strongly water-wet cores.

Table 2. Results of wettability tests.*

	Core initially			Core initially	
Water-based	Strongly ww	Not strongly ww	Oil-based	Strongly ww	Not strongly ww
whole muds	nc(11)		whole muds	↓(9,11), nc (12)	nc(11), ↑(12)
filtrates	nc(1)	nc(1), sl↕(15)	filtrates	↓(1, 6-8)	↓(1,7)
components:			components:		
barite	nc(2)		barite	nc(9), sl↓(10)	nc(9)
salt	nc(2)	nc(2)	surfactants	↓(9,10,16)	↓(9)
lime	sl↑(2)	↑(2)	salts	↓(9), nc(10)	↓(9)
bentonite	nc(2)	↑(2), nc(16)	base oils	nc(9), sl↓(10)	nc (9)
starch	sl↓(2)	↑(16)			
cmc	nc(2)	↑(2,16)			
dextrid		↑(16)			
drispac		↑(16)			
hec		↑(16)			
xanthan		↑(16)			
lignosulfonate	sl↓(2),↓(16)	↑(16)			
pyrophosphate	sl↓(2)				

* ↑=more water-wet (ww), ↓=less ww, nc=no change, sl=slight change

Experimental Procedures

Core Sample. Core samples 1½" in diameter and 1½-2½" in length were cut from a single block of Berea sandstone, with the core axes parallel to the bedding planes. The permeability of the sandstone to air was approximately 600 md. Cores were heated in an oven at 110-120°C for 24 hours, then cooled to room temperature, weighed, and stored in a desiccator until needed. Amott wettability indexes to water of oven-dried Berea sandstone were measured for more than 100 core samples. The average value of I_w for these cores was 0.96.

Fluids. Properties of the brine and refined oil used in wettability measurements are shown in Table 3. All drilling fluid filtrates, chemical additive solutions, brines, and oils used in the experiments were filtered through a 0.45 μm fine membrane overlain by a coarse filter.

Table 3. Properties of brine and oil at 25°C.

Fluid	Composition	Density g/ml	Viscosity cp
Brine	2.5 % NaCl 0.5 % $CaCl_2$	1.018	0.98
Soltrol 130	C_{10} - C_{13}	0.753	1.56

Solutions of Individual Additives. Tests of the wettability altering capability of seven individual additives, widely used in water-based drilling fluids, were conducted in strongly water-wet (untreated) cores that were initially saturated with brine. The additives and concentrations included in this study are shown in Table 4. Physical, chemical, and interfacial properties of the various solutions prepared from these additives, as well as mud and filtrate properties, have been reported previously.[20]

Induced Wetting Conditions. Water-wet to neutral samples were obtained by saturating oven-dried Berea core samples with 25,000 mg/l $CaCl_2$ brine and then treating the core with crude oil.[17-19] Temperature, time, water saturation, and other environmental conditions were varied to give core samples with wettability ranging from strongly water-wet to neutral-wet conditions. Neutral to oil-wet samples were prepared by first saturating a core with 25,000 mg/l $CaCl_2$ brine and then flushing with solutions of asphalt in diesel, followed by aging at high temperature.[20] After aging, cores were flushed with refined oil prior to measurement of Amott indexes.

Table 4. Water-based drilling mud additives.

Additive	Abbrev.	Function	Concentrations
ferrochrome-lignosulfonate	FCLS	thinner and dispersant	0.3 - 5.8 % + 0.1% NaOH
carboxymethylcellulose	CMC	filtration control and viscosifier	0.1 - 0.5 %
sulfonated asphalt	Soltex	shale stability control and lubricant	0.5 - 2.5 %
sulfonated resins and lignite blend	Durenex	high temperature filtration control	0.2 - 1.6 %
polysaccharide	Dextrid	filtration control	0.5 - 2.5 %
polyanionic cellulose	Drispac	filtration control	0.1 - 0.3 %
xanthan gum biopolymer	XC	filtration control and rheology adjustment	0.01 - 0.05 %

Drilling Muds and Filtrates. Seven water-based drilling muds were prepared using chemical additives drawn from those listed in Table 4, plus bentonite or attapulgite, and other inorganic compounds. These drilling fluids are representative of commonly used muds for a variety of geologic and engineering requirements. A Baroid filter press was used to prepare the filtrates. Mud formulations are summarized in Table 5.

Table 5. Water-based drilling mud composition.

DM-#		Clay (%) (B)=Bentonite (A)=Attapulgite	0.1 *N* XOH X=Na or K (%)	Salt (XCl) X=Na or K (%)	CMC (%)	Soltex (%)	Durenex (%)	Drispac (%)	XC (%)	FCLS (%)
1	FCLS-CMC-Soltex	5 (B)	1.0 Na		0.06	1.0				0.4
2	" + Durenex	5 (B)	2.3 Na		0.15	0.6	0.4			1.0
3	KCl-polymer	7 (B)	0.2 K	11.0 K				0.3	0.2	
4	KCl-LS	5 (B)	1.2 K	5.0 K	0.2			0.1		0.5
5	*salt water	7(A)	2.9 Na	12.0 Na	0.2			0.05		1.2
6	sea water	5 (B)	1.2 Na	3.0 Na	0.2			0.1		0.5
7	**low solids	3 (B)	0.8 Na						0.2	

* DM-5 also contains 0.05% aluminum stearate (defoamer).

** DM-7 also contains 0.02% Ben-ex (clay extender) and 0.3% WL-100 (sodium polyacrylate).

Core Treatments. After initial measurements of Amott indexes to water and oil, core samples containing refined oil and brine at S_{wi} were flushed with one of the drilling fluid filtrates under a pressure gradient of 360 psi/ft. Permeabilities to the filtrates were monitored after 3 and 8 pore volumes injected to assess possible plugging. The cores were then submerged in the same drilling fluid filtrate and aged at ambient conditions for an additional seven days. Finally the cores were flushed with 10 PV of brine, followed by 10 PV of Soltrol-130, injected at a pressure drop of 360 psi/ft, after which Amott indexes were remeasured to quantify the effect of exposure to the drilling fluid filtrates on core wettability. The effective oil permeability of the core sample at S_{wi} was also measured for comparison with values of k_o at S_{wi} measured prior to flushing with the drilling fluid filtrates.

Results and Discussion

Solutions of Individual Additives. Wettability indexes measured after flushing strongly water-wet cores with solutions of individual additives are summarized in Fig 1. All the water-based mud additives selected for this study decreased I_w and (except for FCLS) increased I_o of strongly water-wet core samples. In some cases, a dependence on concentration was evident. For example, Soltex and Durenex both increased I_o only slightly until the additive concentrations reached 1.5%. At higher concentrations, the increase in oil imbibition was significant. In addition to wettability alteration, decreases in permeability to oil were observed, especially with the polymer additives. Plugging was observed for Drispac and XC solutions.

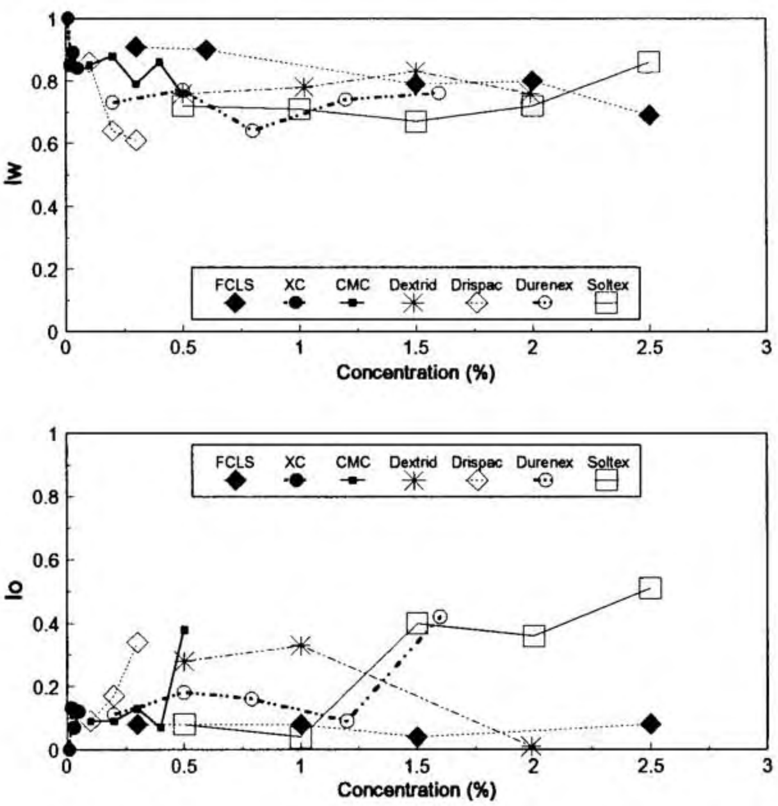

Figure 1. Changes in wettability of very strongly water-wet cores after exposure to water-based drilling mud components.

Drilling Mud Filtrates. The drilling mud filtrates were tested with core samples having a wide range of initial wetting conditions from strongly water-wet to strongly oil-wet. Wettability is characterized by the combined Amott-Harvey index, $I_{w-o}=I_w-I_o$. Thus, the wettability scale defined by I_{w-o} ranges from 1 (strongly water-wet) to -1 (strongly oil-wet).

Results of the effect on wettability of the seven tested mud filtrates are summarized in Fig. 2 as plots of I'_{w-o} (after contact with filtrate) vs. I_{w-o} (before filtrate flushing). There was an overall tendency for cores to become more water-wet. With respect to preservation of wettability, some drilling filtrates are obviously better than others. Least overall change was found for DF4; changes over the range $-0.3 > I_{w-o} > 0.5$ were all less than 0.1 wettability units.

Muds containing Soltex and Durenex (DF-1 and DF-2) caused only a slight change in core samples with initial wettability in the range of weakly water-wet to weakly oil-wet. The greatest changes in wetting were for strongly water-wet (untreated) and the most strongly oil-wet cores.

DF-3, which contained XC polymer and KCl, gave the largest wettability alteration. Except for the strongly water-wet and strongly oil-wet core samples, I_{w-o} was always increased by this filtrate. DF-7, which also contained XC polymer, tended to cause I_{w-o} to be increased as well, suggesting that use of XC polymer, or similar products, should be avoided when preservation of wettability is desired.

The least overall wettability alteration was obtained for DF-4, a mud containing potassium chloride as the electrolyte, FCLS as a thinner and dispersant, and drispac as a filtration control agent. Formulations like DF-4 are commonly used when there is need to inhibit clay swelling and so avoid well-bore damage caused by unstable shales. Thus, the results are encouraging with respect to recovery of cores that have not suffered major changes in wettability, because this mud is suitable for a wide range of formation conditions. DF-4 is highly versatile with respect to depth of drilling and is by no means restricted to its usual application of drilling unstable formations. Further work is needed to understand why this particular mud appears to be advantageous with respect to preservation of wettability. FCLS has been reported to make strongly oil-wet samples less oil-wet[16] and was shown in this work to make strongly water-wet cores less water-wet. Thus, it would normally be recommended for exclusion from bland muds. KCl is known to stabilize clays that partially fill the pore spaces or line the pore walls of many sandstones, but whether these phenomena—clay stabilization and wettability preservation—are related has not been established.

DF-5 and DF-6 are salt water and sea water drilling muds containing 12% and 3% NaCl, respectively. Wettability alteration by filtrates from these two muds is somewhat scattered, but there is an overall tendency for wettability index I_{w-o} to increase.

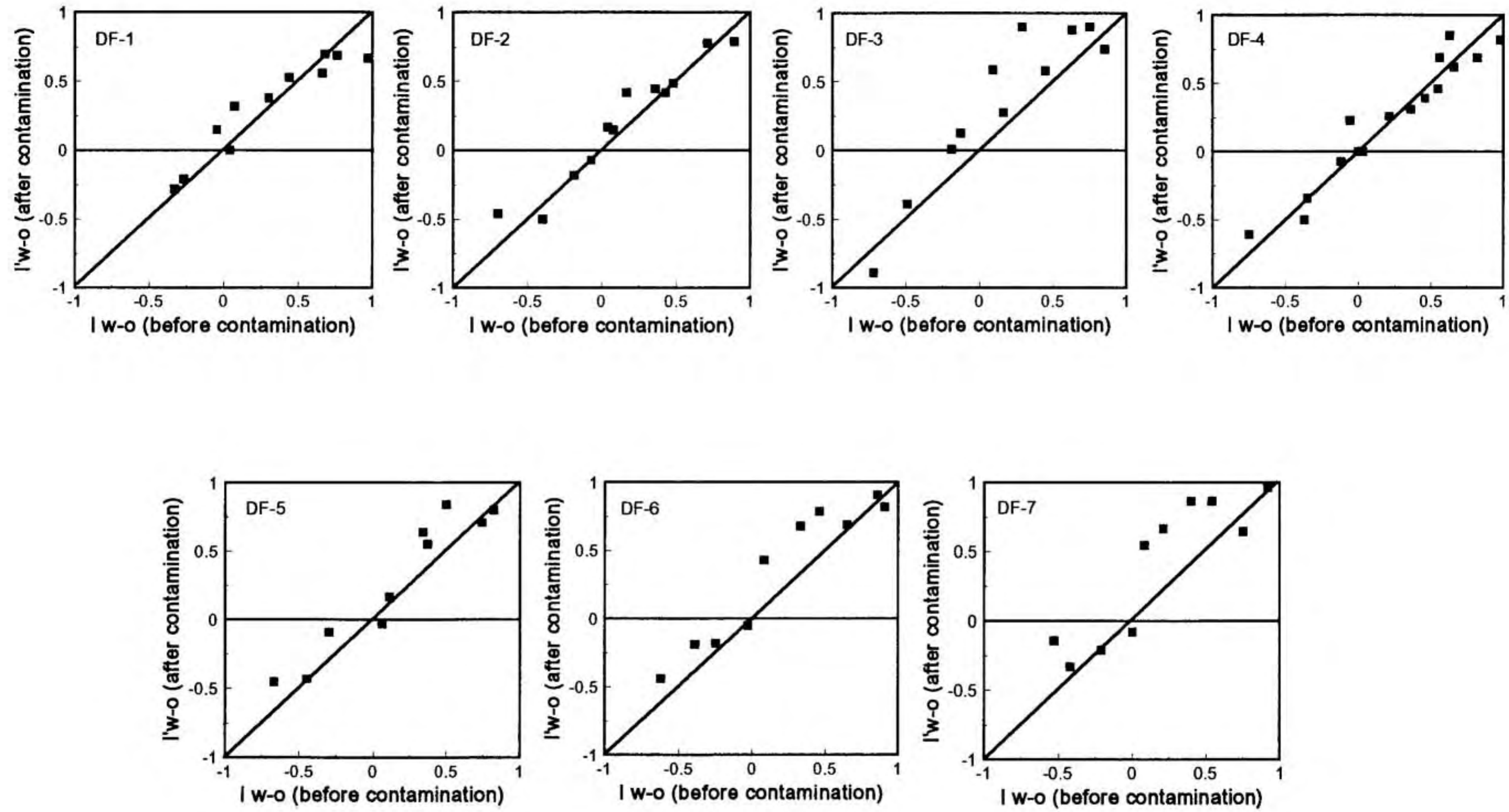

Figure 2. Changes in wettability after exposure to water-based drilling mud filtrates.

Overall, the results of tests with water-based mud filtrates indicate that it is feasible to use practical drilling fluids to recover reservoir core samples with minimal alterations in wettability. The effect of mud filtrates on wettability was always less than that measured for individual drilling mud components. This suggests that the water-based mud additives with the potential to alter wettability may be adsorbed on the clay that is part of the mud formulation. Clay particles are then removed in the filtration step, which simulates flow of filtrate through the mud cake during coring.

With respect to application to specific oil zones, the results provide guidance as to choice of a mud that will minimize wettability alteration. Further systematic tests related to both general and specific situations would help identify mud formulations that minimize wettability alteration for the conditions of interest. Checks on the stability of wettability of fresh and restored state cores after exposure to mud filtrate by laboratory methods would provide further confidence in the selection of appropriate mud formulations.

Conclusions

1. All of the seven chemical additives tested individually lowered the water wetness and raised the oil wetness of initially strongly water-wet core samples. The extent of wettability alteration differed from one chemical additive to another. Polymeric products, in particular, showed strong concentration dependency.

2. Wettability alteration caused by flushing of cores to water-based drilling mud filtrates was generally much less than wettability alteration caused by flushing cores with solution of individual additives used to prepare the various muds. The difference in behavior is ascribed to adsorption of surface active components onto surfaces of the clay minerals contained in the whole mud.

3. Filtrate from a KCl/FCLS/CMC/Drispac drilling mud rendered the minimum wettability alteration of core samples for the complete range of tested wettability states. The change in index I_{w-o} caused by these filtrates was always less than ±0.20, and was less than ±0.1 for cores in the important practical range for reservoirs of moderately oil-wet, through neutral, to moderately water-wet.

Nomenclature

I_w, I'_w = Amott wettability index to water before and after contamination
I_o, I'_o = Amott wettability index to oil before and after contamination
I_{w-o}, I'_{w-o} = Amott-Harvey combined index ($= I_w - I_o$), before and after contamination
k_o = effective permeability to oil, md
S_{wi} = initial water saturation

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