Effect of additives on drilling in hard rock

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Abstract

Rock disintegration processes are usually inefficient and costly operations in mineral beneficiation, mine development and oil well preparations. Thus, there is a strong need for improving the energy efficiency of unit operations such as drilling and comminution. The effects of selected cations and anions on drilling efficiency in a hard rock formation (Dakota Sandstone) were studied. The zeta potentials and the tensile strengths of the drilled samples were measured under similar chemical conditions. The chemicals tested included $MgCl_2$, Na_2CO_3, $AlCl_3$, $NaCl$ and Dodecylammonium chloride. The results indicated that drilling rates can be enhanced or retarded depending on chemical conditions such as the solution pH and the type and concentration of reagents. Drilling data are correlated with mechanical (tensile strength) and interfacial (zeta potential) properties of the rock formation. The mechanisms involved are discussed in light of Rehbinder's and West-

Introduction

Improving drilling efficiency is of prime importance to the mineral and oil industries. Drilling is technically a material-disintegration process and is carried out by subjecting materials to different types of stresses, depending on the drilling bit and applied forces. As with any rock comminution process, drilling is inefficient as far as energy consumption is concerned. Therefore, a cost-effective improvement in the drilling rate is needed. Reported data in the literature indicate that the addition of chemical additives may produce beneficial drilling and grinding effects (Somasundaran and Lin, 1972; El-Shall, 1980; El-Shall and Somasundaran, 1984; Somasundaran and Shrotri, 1995). In addition, there could be unavoidable effects (both beneficial and detrimental) that arise from difficulties in controlling the chemical composition of the environment during drilling.

In the last 50 years, researchers have investigated different ways of increasing drilling efficiency, including the use of chemical agents to influence the surface properties of the drilled solids. Much of this interest resulted from work done by Rehbinder et al. (1944). In their study, it was found that the addition of electrolytes increased the drilling rate in rocks such as granite and quartzite by 20% to 60%. These effects were attributed to the adsorption of ions on the microcrack surfaces, thus preventing the rehealing process. Other researchers (Schreiner and Denim, 1941; Shepherd, 1955; Johnston and Parker, 1957; Shepherd, 1959; Lichtman et al., 1962; Strebig et al., 1969; Westwood, 1972, 1975; Westwood and Latanision, 1972; Westwood et al., 1974; Tweeton et al., additives on drilling rates using various drilling machines. For instance, Schreiner and Denim (1941) found that the penetration rate of crimson quartzite was higher in the presence of $AlCl_3$ than it was in water alone. But this was only when the bit was slightly dull. Also, the effect was found to increase with decreasing machine pressure. Thus, the observed effects could also be dependent on the type of stresses applied. In addition to inorganic reagents, organic additives were also found to enhance drilling rates, as reported by Strebig et al. (1969). The authors concluded that, with a low surface tension additive, the solution would wet the surface better and would cause an increased penetration rate.

Westwood and c[illegible]orkers (Westwood, 1972, 1975; Westwood and Latanision 1972; Westwood et al., 1975) correlated the penetration rates with the surface charge properties. The researchers found that quartz was drilled 13 times faster in water under chemical conditions with a zeta potential of zero. They also reported that there was no change in the drilling rate in a Texas granite using a tricone bit with a zeta-potential-controlling surfactant solution. On the other hand, the same investigators obtained a threefold increase in drilling rate using the same chemical conditions and a diamond bit. They thus attributed the absence of effect to the type of drilling bit.

In addition to the en[illegible]nmental effects on drilling, severa[illegible] reports (Rehbinder, 1931; Schreiner [illegible]nd Denim, 1941; Shepherd, 1955; Shepherd, 1959; Lichtman et al., 1962; Boozer et al., 1963; Engelmann et al., 1967; Westbrook and Jorgensen, 1965, 1968; Strebig et al., 196[illegible]; Westwood, 1972, 1975; Westwood and Latanision, 1972; W[illegible]ood e[illegible]

TABLE 1

Percent change in the drilling rate and tensile strength of Dakota Sandstone in water and sodium chloride solutions as compared to air.

Environment	Percent change pH 3.0		pH 6.0		pH 10.5	
	Drilling	Strength	Drilling	Strength	Drilling	Strength
Air	0.0	0.0	0.0	0.0	0.0	0.0
Water	+25.7	-50.0	+20.7	-32.0	+29.4	-53.0
	+25.1*					
10^{-2} M NaCl	+20.1	-44.0	+33.6	-42.0	+18.0	-42.0

*Cash balance

al., 1974; Tweeton et al., 1976) suggested a strong influence of chemical conditions on the mechanical properties of materials.

For example, Rehbinder (1931) indicated that liquids, water in particular, played an important role in the failure process of materials and that these effects could be amplified by adding surface active reagents. Boozer et al. (1963) reported a decrease in the ultimate strength of sandstone when the pores were saturated with oleic acid or amine solution.

In a different investigation, Hammond and Ravitz 1963 observed that water vapor caused a 40% to 50% decrease in the fracture strength of silica compared to its value in vacuum. Their data showed that environments with polar molecules caused the maximum effect.

An example from their study indicated that sodium citrate decreased the yield strength of Indiana limestone by about 25%, as compared to the value obtained in water alone. Westbrook and Jorgensen (1965) observed that, in almost all the cases, water caused a decrease in rock hardness.

In another study, Westbrook and Jorgensen (1968) reported that organic and inorganic reagents produced different effects on different minerals, such as MgO, CaF_2 and quartz.

They correlated the observed effects with surface-charge properties of the materials in different environments. Engelmann et al. (1967) reported granite to be softer at its isoelectric point.

It is the objective of this research to investigate influence of additives containing anions and/or cations of different valency on the drilling rate in hard rocks. Correlation of drilling rates with mechanical and interfacial properties of drilled rocks, under similar chemical conditions, is another objective of this study.

Experimental

The experimental study included:

drilling experiments using a rotary drill,
tensile strength testing utilizing the "Brazilian test" procedure and
electrokinetic measurements of for the tensile strength and drilling experiments (a zeta meter was used for these measurements).

Materials

Core samples representing a hard rock formation (Dakota Sandstone) were used in this study. The core samples were about 300-mm- (12-in.-) long and 57-mm- (2.25-in.-) diam. For the drilling tests, the core samples were cut into 25.4-mm- (1-in.-) long disks. Inorganic chemicals ($MgCl_2$, Na_2CO_3 and $AlCl_3$) were purchased from Baker Chemical, and dodecylammonium chloride (DDACl) was obtained from Eastman Kodak. Deionized distilled water was used in all tests. The ionic strength was maintained constant by adding 10^{-2} NaCl acquired form Fisher Scientific.

Equipment and procedure

Drilling experiments. Drilling tests were performed using a custom-made setup, which included a 0.75-kW (1-hp) electric motor rotating a drive shaft at 86 rpm. The end of the shaft was fitted with a 9.4-mm-(0.4-in.-) diam polycrystalline diamond bit supplied by International Petroleum Engineering Co. (IPEC). A lathe grip was used as a sample holder. It was connected to the hydraulic cylinder of a manual hydraulic pump containing an actuator and pressure gauge. An electric timer, to control the drilling time, was placed between the electrical outlet and the motor. A schematic of the test setup is shown in Fig. 1.

FIGURE 1

Schematic of the equipment used in the experiment.

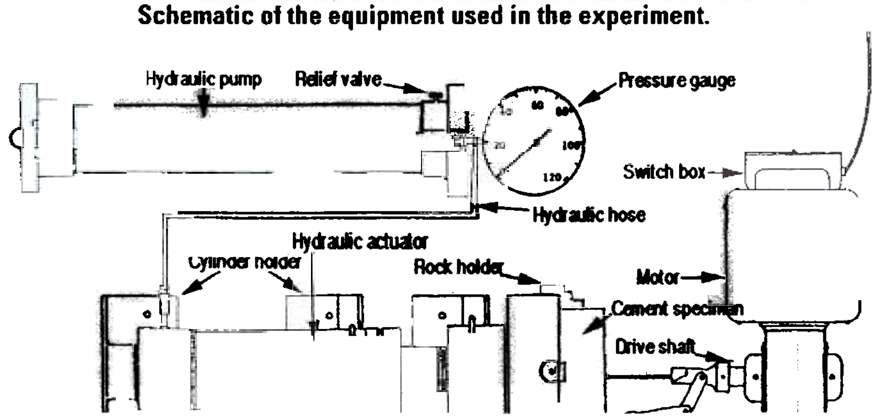


FIGURE 2

Effect of 0.01-M NaCl on the drilling rate and tensile strength of Dakota Sandstone (I.S. = 10^{-2} M NaCl).

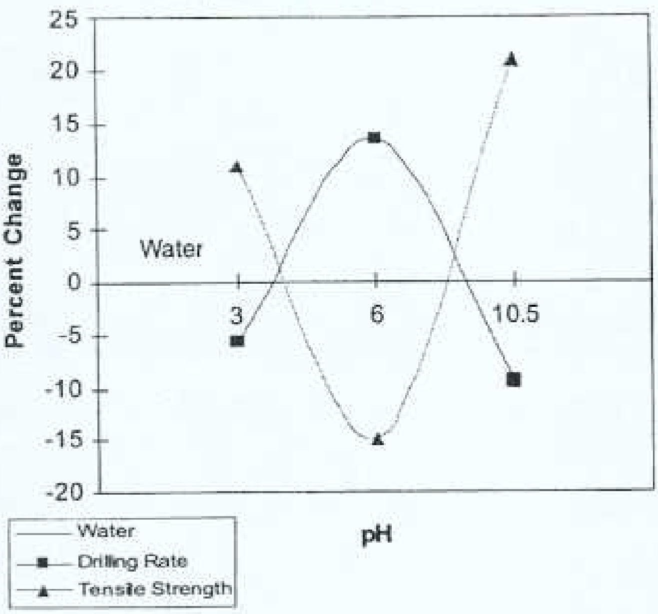
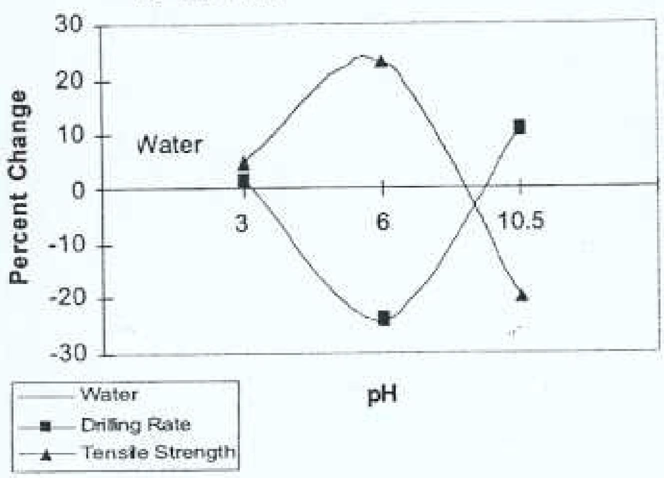


FIGURE 3

Effect of 0.05% magnesium chloride on the drilling rate and tensile strength of Dakota Sandstone (I.S. = 10^{-2} M NaCl).



The prepared sample disk was soaked for 24 hours and then attached to the sample holder. Drilling was conducted for 1.5 min at a constant pressure of 200 kPa (30 psi). Both sides of the sample disks were drilled to provide a duplicate test for each sample. The cuttings were collected, dried and weighed. The weight of the cuttings was compared to the product weight obtained in the control test.

Tensile strength testing. These tests were performed using the indirect tensile strength or the Brazilian test, in which the rock sample is compressed between two parallel ... the following equation (Farmer, 1968)

$$S_T = W/D^2$$

where
W is the applied load and
D is the distance between the points of loading.

In these experiments, samples were taken out of solution and immediately placed between the loading platens of a 110-t- (100-st-) capacity hydraulic jack. The load application rate was set at 450 kg/min (1,000 lb/min). The test was repeated five times, and the average results are reported.

Electrokinetic measurements. For zeta potential measurements, core samples were ground in an agate mortar and then dry screened at 45 μm (325 mesh). Then, 0.5 g (0.02 oz) samples of -45 μm (-325-mesh) material were mixed with the desired solution at the required pH and then conditioned for 30 min by agitation using a wrist-hand shaker. This suspension was then transferred to the zeta meter cell.

Results and discussions

Effect of water. Water is found to increase the drilling rate in sandstone as compared to the values obtained in air, as can be seen in Table 1. The results show that an increase of 20% in drilling rate could be achieved at all pH levels, as compared to drilling in air. On the other hand, tensile strength of the same samples has decreased by at least 33%. Also, because NaCl is added to all the tests to control the ionic strength, the effect of NaCl on drilling rate and mechanical properties of sandstone are also determined, as shown in Table 1. A slight increase in drilling rate in neutral solutions is suggested by the data. A detrimental effect is displayed at acidic and alkaline pH ranges (percent change values showed a decrease of about 20% at pH 3.0 and at pH 10.5). The tensile strength, however, decreased by about 42% with NaCl addition at all pH levels. Thus, in comparison to water, the drilling rate in sodium chloride solutions is found to increase or decrease depending on the pH conditions, as suggested by the data shown in Fig. 2. It is interesting to note the inverse relationship between tensile strength and drilling rate.

Effect of divalent ions. The data in Fig. 3 shows the effect of $MgCl_2$ on both drilling rate and tensile strength, as compared to water alone. An appreciable (>20%) decrease in the drilling rate is observed in the neutral pH range. Increasing or decreasing the solution pH results in reducing this detrimental effect. It is interesting to mention that, although the drilling rate in these solutions is about 20% less than in water, it is still higher than the drilling rate in air. Also, in this case, it can be stated that as the additive decreases the tensile strength, an improvement in the drilling rate is obtained and vice versa. In $MgCl_2$ solutions, the observed increase in drilling rate and decrease in tensile strength in the alkaline solution may be attributed to the adsorption of positively charged surface active species ($MgOH^+$) on the negatively charged sandstone particles. The change in zeta potential value form negative to positive when $MgCl_2$ is added at pH 10.5 is a good indication of adsorption of $Mg(OH)^+$

TABLE 2

Zeta potential values, and percent change in drilling rate and tensile strength of Dakota Sandstone in presence of different environments as compared to NaCl solutions (I.S. = 10^{-2} M NaCl).

	pH 3.0 % Change			pH 6.0 % Change			pH 10.5 % Change		
Environment	Drilling rate	Tensile	Zeta potential, mV	Drilling rate	Tensile	Zeta potential, mV	Drilling rate	Tensile	Zeta potential, mV
Water	4.3	-10.4	-7.0	-12.4	+17.3	-17.0	-17.0	9.7	-30.0
	3.8*			-6.8*					
10^{-2} M NaCl	0	0	-7.0	0	0	-13.0	0	0	-27.0
0.01% $AlCl_3$	-15.7	+15.6	+8.0	-1.4	+1.9	+18.0	-3.7	+5.1	-26.0
	-15.4*	+18.8*		-4.5*			-1.5*	+6.5*	
0.05% $MgCl_2$	-2.9	+5.3	-4.0	-24.5	+24.1	-5.0	+13.5	-19.4	+5.0
	-4.1*						+7.3*		
0.2% Na_2CO_3	-5.4	+13.0	-7.0	-8.0	+21.8	-14.0	+7.4	-12.	-33.0
	-7.2*			-11.7*					
10^{-5} M Amine	-11.6	+6.2	-6.0	-20.0	+22.9	15.0	+8.7	-6.4	-20.0
	-8*	+12.4*							

*Duplicate tests

The effect of divalent anion (CO_3^{-2}) is studied by using sodium carbonate solutions at different pH conditions. The results are given in Fig. 4 and in Table 2. The data indicate that the addition of Na_2CO_3 causes a decrease in the drilling rate and an increase in the tensile strength in acidic and neutral pH solutions. In alkaline solutions, however, an improvement in the drilling rate is observed. Zeta potential data, given in Table 2, suggest a slight change in zeta potential, indicating no adsorption is taking place. It is also well known that CO_3^{-2} does not adsorb on negatively charged sandstone. The reasons for the observed changes in drilling rate and strength values as the pH increases are not clear at this time, and further investigation is needed in this regard.

Effect of trivalent cations. To study the effects of trivalent cation, (Al^{+3}), $AlCl_3$ solutions were used, and the results are plotted in Fig. 5. The results show that this additive influences the tensile strength and drilling rate only in acidic conditions. These effects could be due to adsorption of positively charged cations (Al^{+3} and $Al(OH)_2^+$) on the negatively charged sandstone surface. These species are predominant at low pH values. This adsorption could also be responsible for the changes in zeta potential values given in Table 2.

Effect of dodecylammonium chloride (DDACl). The effect of organic additives such as DDACl was investigated, and the results are shown in Fig. 6. Also, in this case, the inverse relationship between tensile strength and drilling rate can be noted. A decrease of nearly 20% in the drilling rate is evident in the neutral pH range. However, a small measurable beneficial effect is obtained in the alkaline medium (pH 10.5). This effect could possibly be attributed to the adsorption of positively charged, highly surface-active species (ion-molecular complexes) in this pH range on a negatively charged sandstone surface. The decrease in zeta potential value at this pH (Ta... 2) may also be due to the adsorption of such highly surface-active species (in alkaline amine solutions) is confirmed by several researchers, as reviewed by El-Shall (1980).

Conclusions

The effects of different additives on drilling rate, tensile strength and zeta potential of sandstone (representing hard rock formations) were investigated. Under the tested conditions, the results suggest the following:

Drilling rates in wet conditions are much higher than in air.
The drilling rate can be enhanced, compared to drilling in water alone, under selected conditions of reagent type and pH solutions.
The drilling rate is found to increase under chemical conditions that reduce the tensile strength.

FIGURE 4

Effect of 0.02% sodium carbonate on the drilling rate and tensile strength of Dakota Sandstone (I.S. = 10^{-2} M NaCl).

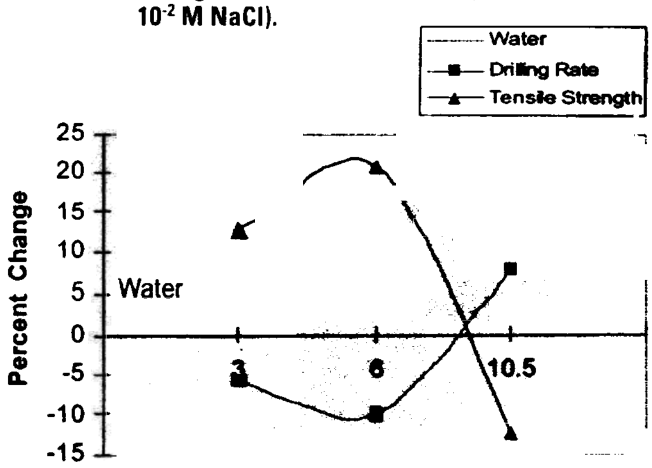


FIGURE 5

Effect of 0.01% aluminum chloride on the drilling rate and tensile strength of Dakota Sandstone (I.S. = 10^{-2} M NaCl).

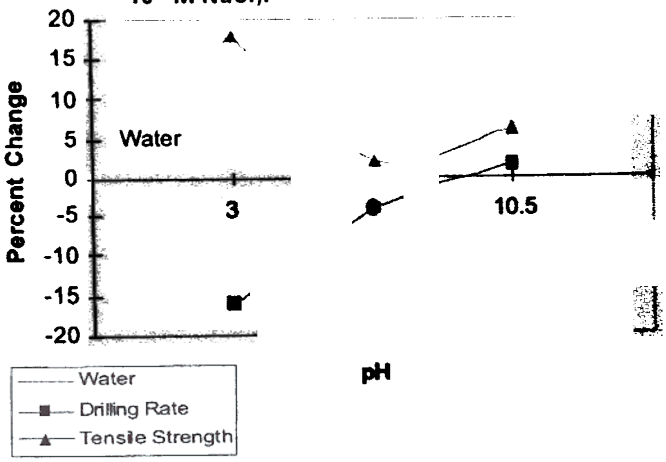
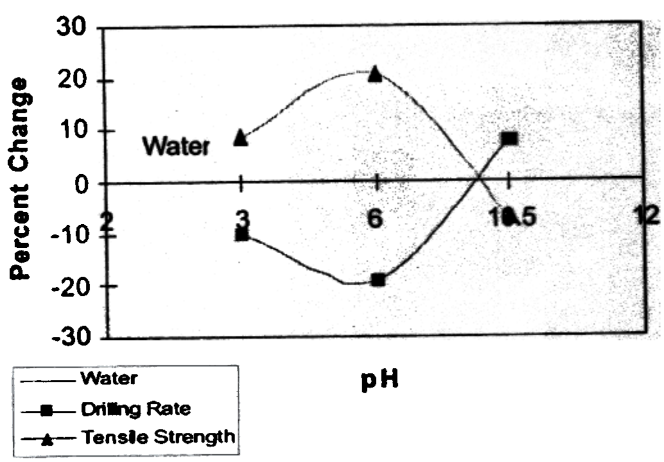


FIGURE 6

Effect of DDACl on the drilling rate and tensile strength of Dakota Sandstone (I.S. = 10^{-2} M NaCl).



There is no obvious relationship between either the drillability or tensile strength and zeta potential of the samples studied.

Reported data may be used as an indication of the possible effects of studied reagents on mechanical properties of these rock formations. However, a more comprehensive study is needed to simulate the industrial conditions.

Further research is recommended to investigate the mechanism-controlling effects of different environments on the disintegration processes. ■

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