Effect of additives on drilling in hard rock

H. El-Shall, R. Haecker, P. Somasundaran and S. Gupta

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 reheating 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., 1977) also reported that the presence of chemical additives on drilling rates using various drilling machines. For instance, Schreiner and Denim (1941) found that the penetration rate of a certain quartzite was increased by 60% under certain conditions. 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, 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 cause an increased penetration rate.

Abstract

Rock disintegration processes are usually inefficient and costly operations in mineral beneficiation, mining 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 MgCl₂, Na₂CO₃, AlCl₃, NaCl and Dodecylaminonium 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 Westwood's work.
<table>
<thead>
<tr>
<th>Environment</th>
<th>pH 3.0</th>
<th></th>
<th>pH 6.0</th>
<th></th>
<th>pH 10.5</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>Drilling</td>
<td>Strength</td>
<td>Drilling</td>
<td>Strength</td>
<td>Drilling</td>
<td>Strength</td>
</tr>
<tr>
<td>Water</td>
<td>+25.7</td>
<td>-50.0</td>
<td>+20.7</td>
<td>-32.0</td>
<td>+29.4</td>
<td>-53.0</td>
</tr>
<tr>
<td>$10^{-2}$ M NaCl</td>
<td>+20.1</td>
<td>-44.0</td>
<td>+33.6</td>
<td>-42.0</td>
<td>+18.0</td>
<td>-42.0</td>
</tr>
</tbody>
</table>

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 ($\text{MgCl}_2$, $\text{Na}_2\text{CO}_3$ and $\text{AlCl}_3$) 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 $10^{-2} \text{NaCl}$ acquired from 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.

![Schematic of the equipment used in the experiment.](image-url)

Experimental
The experimental study included:
- drilling experiments using a rotary drill,
- tensile strength testing utilizing the “Brazilian test” procedure,
- and electrokinetic measurements of
the following equation (Farmer, 1968)

\[ S_t = \frac{W}{D^2} \]

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-ton- (106-stt-) 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 MgCl₂ 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 MgCl₂ 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 (Mg(OH)⁺) on the negatively charged sandstone particles. The change in zeta potential value form negative to positive when MgCl₂ is added at pH 10.5 is a good indication of adsorption of Mg(OH)⁺ species.
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).

<table>
<thead>
<tr>
<th>Environment</th>
<th>pH 3.0</th>
<th>% Change</th>
<th>Zeta potential, mV</th>
<th>pH 6.0</th>
<th>% Change</th>
<th>Zeta potential, mV</th>
<th>pH 10.5</th>
<th>% Change</th>
<th>Zeta potential, mV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drilling rate</td>
<td>Tensile</td>
<td></td>
<td>Drilling rate</td>
<td>Tensile</td>
<td></td>
<td>Drilling rate</td>
<td>Tensile</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>4.3</td>
<td>-10.4</td>
<td>-7.0</td>
<td>12.4</td>
<td>-17.0</td>
<td>-17.0</td>
<td>9.7</td>
<td>-3.6</td>
<td>-30.0</td>
</tr>
<tr>
<td>0.01% AlCl₃</td>
<td>-15.7</td>
<td>+15.6</td>
<td>+8.0</td>
<td>-1.4</td>
<td>+1.9</td>
<td>+18.0</td>
<td>-3.7</td>
<td>+5.1</td>
<td>+26.0</td>
</tr>
<tr>
<td>0.05% MgCl₂</td>
<td>-2.9</td>
<td>+5.3</td>
<td>-4.0</td>
<td>-24.5</td>
<td>+24.1</td>
<td>-5.0</td>
<td>-13.5</td>
<td>-19.4</td>
<td>-5.0</td>
</tr>
<tr>
<td>0.2% Na₂CO₃</td>
<td>-5.4</td>
<td>+13.0</td>
<td>-7.0</td>
<td>-8.0</td>
<td>+21.8</td>
<td>-14.0</td>
<td>+7.4</td>
<td>-12.0</td>
<td>-33.0</td>
</tr>
<tr>
<td>10⁻⁴ M NaCl</td>
<td>-11.6</td>
<td>+6.2</td>
<td>-6.0</td>
<td>-20.0</td>
<td>+22.9</td>
<td>+15.0</td>
<td>+8.7</td>
<td>-6.4</td>
<td>-20.0</td>
</tr>
</tbody>
</table>

*Duplicate tests

The effect of divalent anion (CO₃⁻²⁻) 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 Na₂CO₃ 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 CO₃⁻²⁻ 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, (Al³⁺), AlCl₃ 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 (Al³⁺ and Al(OH)₃⁺) 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 (DDACI). The effect of organic additives such as DDACI 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 (Table 2) may also be due to the adsorption of such highly surface-active species (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).

![Graph showing effect of 0.02% sodium carbonate on drilling rate and tensile strength of Dakota Sandstone.](image_url)
FIGURE 5

Effect of 0.01% aluminum chloride 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.

Acknowledgment

Partial financial support from the Engineering Research Center (ERC) for Particle Science and Technology at the University of Florida, the National Science Foundation (NSF) under grant EEC-94-02989 and the Industrial Partners of the ERC is acknowledged.

References


