Microbit Studies of the Effect of Fluid Properties and Hydraulics on Drilling Rate, II

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Discussion of this paper is invited. Three copies of any discussion should be sent to the Society of Petroleum Engineers office. Such discussion may be presented at the above meeting and, with the paper, may be considered for publication in one of the two SPE magazines.

ABSTRACT

Microbit studies presented to the SPE of the AIME in 1966 (SPE 1520) showed that in one rock under fixed conditions of bit weight, rotary speed, and differential pressure, drilling rate could be expressed as a simple power function of mud flow properties and hydraulic parameters. A logical question arose: "Are these reported results general?"

To resolve this question, the results of additional microbit studies are reported in this paper. These tests were conducted with bit weights 500 pounds less and greater than the original 1000 pounds test condition, rotary speeds of 150 rpm and 45 rpm in addition to the original 75 rpm value, and differential pressures of 0 and 50 psi in addition to the original 500 psi test condition. Tests were also run in Carthage marble as well as additional tests in the original Indiana limestone.

Under all of these conditions, the original relationship of rate of penetration to fluid properties and hydraulics was unchanged. Changes in the various parameters caused changes in the drilling rate, but not in the effect of fluid properties and hydraulics.

There was no detectable interaction between the variables, indicating that an equation of the form,

$$ R = k f(W,N) \left( \frac{k_c \theta}{du} \right)^a $$

can be satisfactorily used for calculating drilling rate.

INTRODUCTION

An earlier paper, "Microbit Studies of the Effect of Fluid Properties and Hydraulics on Drilling Rate" (SPE 1570, published in 1966), presented the results of a laboratory study indicating that drilling rate can be expressed as an exponential function of a pseudo Reynolds number involving flow rate, nozzle size, and fluid viscosity and density. For non-Newtonian fluids, the "viscosity" is that at hole bottom, near bit-nozzle, shear rates. A relatively simple expression for drilling rate,

$$ R = k R_e^{0.5} $$

can be used to cover the range of greatest variation—that is, for values of the Reynolds number between about 5 and 100. The expression used for the Reynolds number is:
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\[ R_e = \frac{0.8 Q \rho}{d \mu}, \]

where \( Q \) is the flow rate in gallons per minute, \( \rho \) is the specific gravity of the mud, \( d \) is the nozzle diameter in inches, and \( \mu \) is the mud viscosity in centipoise.

This laboratory correlation was obtained in Indiana lime at constant conditions of 1000 pounds bit weight, 75 rpm rotary speed, and 500 psi differential pressure. These experiments, however, left unanswered the questions of interaction between the Reynolds number function and the mechanical (bit weight and speed) and environmental (differential pressure and rock type) variables. Further, the available equipment had limited the maximum Reynolds number function to a value of about 135.

The experiments reported here were designed to answer these questions and to expand the limits of the earlier tests.

DISCUSSION

Reynolds Number Range

To increase the range of Reynolds number function that could be investigated without increasing our capital equipment investment, a Halliburton HT 400 pump truck was hired on an hourly basis. With the pump truck, function values up to about 330 were obtained before the pressure limits of the laboratory piping manifold were reached. Results from this test are shown with the earlier data in Figures 1 and 2. The "saturation" effect implied by the original work was verified, showing that still higher test values of the function may not be justified. These measurements more than doubled the original range of the investigation; in this extended range, drilling rate still increases with increasing Reynolds number, but at a reduced (and possibly uneconomic) rate.

Bit Weight

To determine the interaction of the Reynolds number function and weight on the bit, additional tests were run in Indiana lime at 500 and 1500 pounds as well as the original 1000 pounds bit load, and at 75 rpm and 500 psi differential pressure. Results of these tests in the form of computer correlations are shown in Table I and in Figure 3. The slopes of the lines are essentially the same, and the limits of variability were the same, showing no significant interaction between the Reynolds number function and bit weight.

Rotary Speed

A series of tests were run in Indiana lime at rotary speeds of 45 and 150 rpm as well as the original speed of 75 rpm, 1000 pounds bit load, and 500 psi differential pressure, to determine the interaction with rotary speed. The results of these tests are shown in Table I and in Figure 4. As in the weight testing, the near uniform slopes and range of variation indicate no interaction between rotary speed and the drilling rate-Reynolds number correlation.

Differential Pressure

To determine the effect of differential pressure on the drilling rate-Reynolds number function correlation, additional tests were run at pressures of 50 and 0 psig as well as the original value of 500 psig between the borehole and the formation pore pressure. In Table I and in Figure 5, these results are compared with the original 500 psi machine correlation. Reducing the differential pressure has the effect of reducing the "hardness" of the rock; that is, the coefficient \( k \) increases, but the exponent on the Reynolds number function remains unchanged. This means that the drilling rate correlation is independent of differential pressure and that large-rig scaling studies can be expedited by conducting the tests at atmospheric pressure.

Formation

To determine the effect of formation on the correlation, tests were run in Carthage marble. This is an essentially impermeable material, somewhat harder than the 10 md Indiana lime used in the original tests. To obtain more comparable rates of penetration, the bit load was increased to 1500 pounds and the differential pressure was reduced to 50 psi. The results of this series of tests are shown in Table I and plotted as machine correlations in Figure 6. Although the upper range of the investigation was limited, the results appear to correspond very closely to those obtained on the tests in Indiana lime. That is, the harder rock has a reduced drillability coefficient, \( k \), but the exponent of the Reynolds number function term is the same as that obtained in the tests with lime, indicating that the drilling rate correlation is independent of formation.

CONCLUSIONS

The microbit tests have led to the development of a response function for the
microbit machine that statistically gives less than 10 percent error 95 percent of the time. We consider this to be excellent for a multivariable problem of this nature. The lack of interaction between the variables indicates that the system is linear and that useful real-world solutions may be developed with further research and testing.

Equally as important as the response function, but more difficult to determine, is the answer to the question, "Why is this the nature of the response?" A power law model with limits which fits the experimental data was chosen for simplicity—not because it describes the physics of the drilling process. In other words, we don't yet know why, but microbit tests show that:

1. Drilling rate may be expressed as an exponential function of bottom hole or near bit-nozzle Reynolds number.

2. This relation can be simply expressed as
   \[ R = k(R_e)^{0.5}, \quad 5 < R_e < 100. \]
   For other ranges of \( R_e \), a different exponent will probably give a better result.

3. This relation is independent of bit weight, bit speed, and differential pressure between the borehole and formation, the only pressure strongly affecting drilling rate; tests in two types of rock indicate that it is also independent of formation type.

4. Changing the differential pressure between the formation and borehole has the same effect as changing the formation; reducing the pressure merely increases the drillability of the formation. This means that the scaling tests can be run at atmospheric pressure.

### TABLE I

**RMS CORRELATION PARAMETERS FOR POWER LAW DRILLING-RATE MODEL**

\[ R = k \left( \frac{k_d}{du} \right)^{\alpha} \]

<table>
<thead>
<tr>
<th>RPM</th>
<th>H</th>
<th>AP</th>
<th>( k )</th>
<th>( \alpha )</th>
<th>( n )</th>
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<td>500</td>
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<td>65</td>
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<td>500</td>
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<td>0.50</td>
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<td>0</td>
<td>2.79</td>
<td>0.50</td>
<td>105</td>
</tr>
</tbody>
</table>

**Indiana Lime**

**Carthage Marble**

75 1500 50 2.22 0.464 150
Fig. 1 - Drilling rate vs Reynolds number function in Indiana Lime drilled at 1000 bit weight and 75 rpm with a differential pressure of 500 psi.

Fig. 2 - Logarithm of drilling rate vs logarithm of Reynolds number function in Indiana Lime drilled at 1000 lb bit weight and 75 rpm with a differential pressure of 500 psi.

Fig. 3 - Logarithm of drilling rate vs logarithm of Reynolds number function for three bit weights - other operating conditions as shown.

Fig. 4 - Logarithm of drilling rate vs logarithm of Reynolds number function for three different rotary speeds - other operating conditions as shown.

Fig. 5 - Logarithm of drilling rate vs logarithm of Reynolds number function for three different differential pressures - other operating conditions as shown.

Fig. 6 - Logarithm of drilling rate vs logarithm of Reynolds number function for two different formations - operating conditions as shown.