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# DRILLING RATE CHANGES WHEN AIR DRILLING IS SWITCHED TO MIST DRILLING

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Bartlesville Energy Research Center
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## CONTENTS



## ILLUSTRATIONS



## TABLES

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C. Ray Williams 1/

## ABSTRACT

Eight shallow (30-foot-deep) holes were drilled in four formations to determine if a significant portion of the reduction in penetration rate that usually occurs when air drilling is changed to mist drilling (air driller's rule-of-thumb estimates average about one-third loss) might be due to the physical action of drilling a wet, soapy rock. The results showed an average loss of 9.3 percent in the four formations drilled, with the greatest loss occurring in limestone. The softest formation (claystone) showed only a 1.2- percent reduction in penetration rate; the two sandstones averaged 10.0- percent loss; and the limestone showed a significant 15.8-percent loss. This indicates that the loss of penetration rate due to wetting the rock while mist drilling is small but would be significant when drilling a long interval.

The findings indicate that when drilling hard rocks at the surface with mist instead of air, a penetration rate loss of approximately 12 percent (compared to the drilling rate with air) will occur due to the effect of jetting the soapy water through the bit onto the formation being drilled. A further investigation is required to determine if the same effect occurs while drilling at depth under varying hydrostatic heads and to determine if the effect can be eliminated to provide increased drilling rates.

## INTRODUCTION

The drilling industry uses air drilling when economically feasible because faster penetration rates are usually obtained when air is used as the circulating medium instead of drilling mud. Unfortunately, certain problems associated with air drilling limit its use to only a few areas in the United States. This report describes one of the phenomena affecting drilling rates while attempting to drill with air as the circulating medium.

When water is encountered during air drilling, the usual procedure is to attempt to convert to mist drilling. Mist drilling is performed by pumping small

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1/ Petroleum engineer

volumes of a concentrated soap and water mixture into the air stream at the surface. The total mixture flows down the drill pipe, through the bit nozzles, and into the annulus where the resulting soap bubbles reduce the density of the produced water thereby allowing the air to lift the water and drill cuttings to the surface. If the quantity of produced water is not too great, and problems such as water-sensitive (swelling) clays or sloughing shale do not occur due to water wetting, then mist drilling can be continued until additional water is encountered or other problems occur.

In past drilling operations, a significant decrease in penetration rate has been observed when switching from air to mist drilling. Some drillers use a rule-of-thumb that predicts a one-third decrease in penetration rate when making this change. Actually, as much as 50- to 75- percent decrease has been observed when light drilling weight was being used to control deviation and prevent a crooked hole. These observations, and a desire to reduce the penetration rate losses, prompted this field experiment.

Underbalanced drilling--that is, hydrostatic pressure less than in situ pressure--provides faster drilling rates than overbalanced drilling and, since air drilling is the ultimate in underbalanced drilling, it follows that this is the main reason for higher penetration rates while drilling with air. Converting from air drilling to mist drilling is usually done because water has been encountered; therefore, the pressure head on the formation changes from a column of air to a column of aerated soapy water. This increase in hydrostatic head is generally considered to be the major reason for the decreased drilling rate that occurs when changing from air to mist, but the drilling rate might also be adversly affected by the physical action of drilling a rock that is continously being wetted with a soapy spray through the bit.

It was conceivable that if the soapy water used for mist drilling could be injected into the annulus immediately above the drill bit then the bit would still be drilling a dry rock and a penetration rate increase might be realized. This could be accomplished with concentric drill pipe or a downhole separator with a ported sub above the bit. Before the acutal purchase and construction of experimental equipment, some evidence was needed to prove whether the soapy water spraying through a drill bit acutally does affect the drilling rate of various rocks. Methods to determine the amount of this effect were considered, and these field experiments were conceived and performed to determine that effect.

Since changes in hydrostatic head cause a dramatic effect on penetration rates, the effect of the wetting action on the rock could only be evaluated by drilling rocks at the surface where the hydrostatic head should be negligible. The experiment was performed in the field by locating outcroppings of suitable rocks, drilling one 30-foot hole with air, and then moving about 5 feet and drilling a second hole with mist. Acceptable data were obtained by holding all other drilling variables constant.

## FIELD TESTS

### Location

A contractor with a small hydraulic-controlled drilling rig was located in Phoenix, Arizona, and only minor equipment modifications were necessary to provide good control of other drilling variables. The location of the contractor and equipment influenced the selection of an area of rock outcrops in northeast Arizona as the work site. The four outcrops selected were the Coconino Sandstone, a claystone, the Moenkopi Sandstone, and the Kaibab Limestone. The drilling was performed on Arizona State highway rights-of-way where road cuts allowed a visual inspection of the rocks to be drilled.

Cores for rock characterization were taken midway between the holes at three of the locations. No core was taken in the claystone because it was unlikely that good core data could be obtained owing to the soft, stratified nature of the formation. The core analysis data showing rock characteristics are presented in table 1; however, water saturation measurements were not taken because one of the requirements for drill site selection was that the site be more than 30 feet above the local water table. All of the air holes "dusted" throughout the drilled interval, and no free water was observed.

### Rig Equipment and Controls

The small, mobile, hydraulic rig provided a visual pointer against a footage tape which allowed accurate incremental measurement and timing. The weight on the bit was accurately held constant by a hydraulic "pulldown" system which was calibrated before the experiment. A calibrated tachometer was used to indicate rotary speed, but the sensitivity of this control was low, and this measurement was verified by hand timing at regular intervals. The rig also had a 60-gallon pressure tank which allowed control of the volume of mist by using differential pressure to force the soapy water through a calibrated needle valve. A power swivel provided a smooth, steady source of torque for drilling. A portable air compressor was always operated at the same throttle and pressure settings. The equipment provided good control of the drilling variables, but in those instances where possible discrepancies existed, the data obtained have been deleted from the comparison. All of the holes were drilled with 4 3/4-inch, hard-formation, milled tooth bits with an air volume of approximately 360 Mcfd. In order to reduce bit dullness as a factor in the drilling rate comparisons, four new bits were used in the four holes drilled in the Conconino and Moenkopi. These bits were undamaged and were used in the other four holes.

TABLE 1. - Core analysis data: air-mist penetration rate experiment

| Formation | Depth, feet | Porosity, percent | Permeability, millidarcies | Compressive strength lb/in$^2$ | Remarks |
|---|---|---|---|---|---|
| Coconino Sanstone. | 8.6 | 18.9 | 306 | 4,800 | Appeared homogeneous. |
| | 10.1 | 17.9 | 290 | 4,300 | |
| | 11.6 | 18.2 | 399 | 5,400 | |
| | 13.4 | 18.2 | 568 | 5,400 | |
| Average | | 18.3 | 391 | 4,975 | |
| Moenkopi Sandstone. | 13.8 | 9.7 | 3.6 | 8,800 | Uniform matrix with occasional wafer thin bedding. |
| | 15.2 | 8.2 | 4.6 | 7,200 | |
| | 16.9 | 8.2 | 9.5 | 6,800 | |
| | 18.3 | 8.7 | 3.5 | 6,300 | |
| | 19.8 | 9.8 | 6.5 | 5,400 | |
| Average | | 8.9 | 5.5 | 6,900 | |
| Kaibab Limestone. | 8.1 | 14.4 | 3.5 | 8,800 | Limestone. |
| | 9.5 | 13.8 | 2.3 | 8,800 | Do. |
| | 11.7 | 20.1 | 48.2 | 5,400 | Sandy lime. |
| | 13.3 | 21.3 | 64.6 | 5,900 | Do. |
| | 15.8 | 20.0 | 71.4 | 3,200 | Limy sand. |
| | 17.8 | 21.5 | 90.6 | 2,900 | Do. |
| Average | | 18.5 | 46.8 | 5,800 | |

## Coconino Sandstone Test

The first drill site was an outcrop of Coconino Sandstone about 5 miles southeast of Holbrook, Arizona. The weight on bit was 8,000 lb, and rotary speed was 48 rpm. The intervals from 9 to 16 and 19 to 28 feet were drilled in 61.5 minutes using air and 69 minutes using mist. This shows that the mist drilling was 12.2 percent slower than the air drilling. Drilling time for the 3-foot interval from 16 to 19 feet was deleted as not representative because of mechanical problems on the mist hole. The average rock characteristics of four test points from the Coconino Sandstone core are porosity, 18.3 percent; permeability, 391 md; and compressive strength, 5000 psi. The cored section showed a fairly uniform homogeneous sandstone.

Figure 1 shows the drilling rate curves obtained. All of the drilling curves have been plotted using a running average to reduce the significance of minor discrepancies in measurements of depth or timing. This was the first hole drilled, and the ragged appearance of the early portion of the curves is probably an indication of crew training on parameter control. In retrospect, this location probably should have been redrilled to obtain more uniform curves similar to the latter portion of the curves.

## Claystone Test

The second location was drilled in a claystone in an attempt to simulate drilling a competent shale. The rotary speed was 56 rpm, and the bit weight was 4,000 lb from 8 feet to 23 feet and then was increased to 6,000 lb. When wetted by the mist, this formation became sticky and soft, but it drilled satisfactorily with both the mist and the air.

The overall time for drilling 21 feet from 8 to 30 feet (1 foot deleted) was 41 1/2 minutes with air and 42 minutes with mist for a decrease in penetration rate of only 1.2 percent. Since a larger decrease had been expected, this result was surprising. This information would indicate that mist drilling could be utilized for dust control in soft-formation, surface-hole drilling, such as mining operations, without a significant loss of penetration rate. No core samples were taken in the claystone owing to the incompetent stratified nature of the formation. Figure 2 shows the drilling rates obtained in the claystones.

No outcrops of competent shale were available near the work area, and the claystone was selected to simulate drilling in shale; however, the selection may have been a poor choice since the drilling results do not substantiate previous oilfield experience while drilling shale with air and mist.

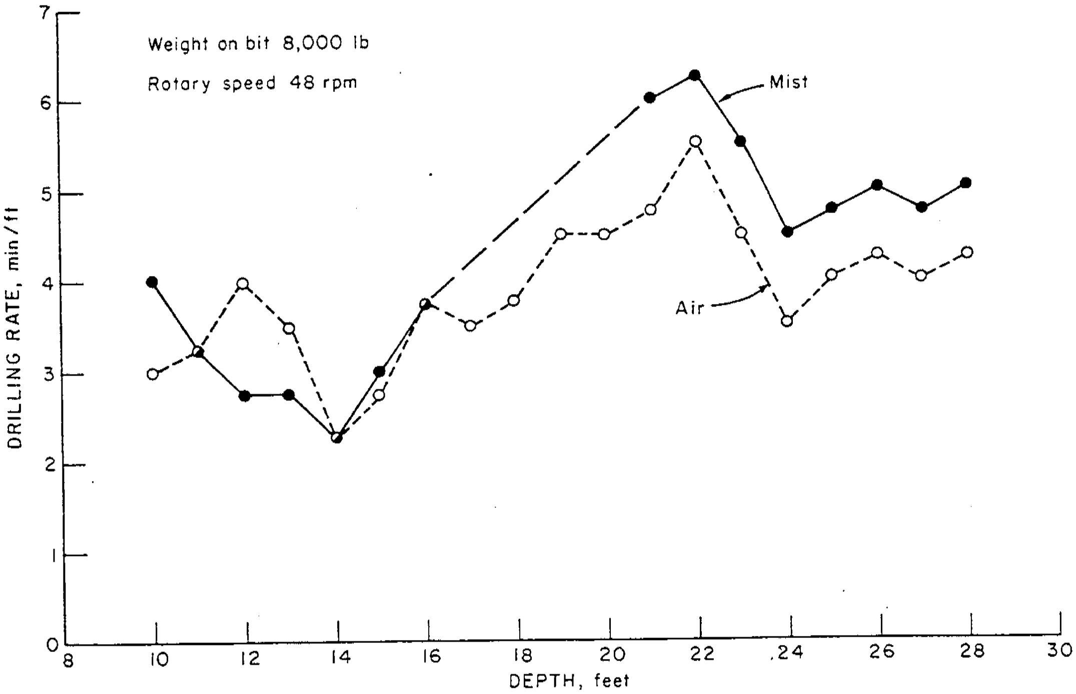


FIGURE 1.- Drilling Rate vs. Depth, Coconino Sandstone.

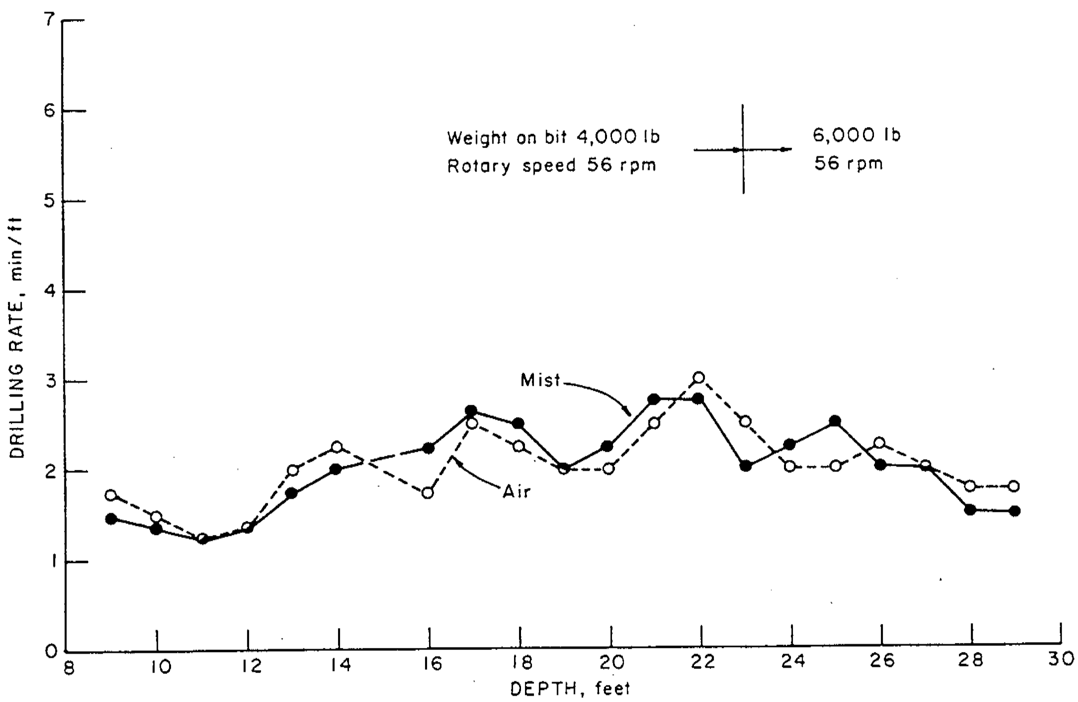


FIGURE 2.- Drilling Rate vs. Depth, Claystone.

## Moenkopi Sandstone Test

Location No. 3 was a Moenkopi sandstone which was drilled with a bit weight of 10,000 lb and a rotary speed of 56 rpm. The total drilling time from 10 to 31 feet was 40 and 54 minutes with air and mist, respectively, resulting in a 35-percent decrease in penetration rate while mist drilling. These data fell more in line with what had been expected when the experiment was begun; however, portions of the data appeared questionable and the apprehension became justified when a subsequent core from 10 to 20 feet recovered a near vertical fracture or joint. When the direction and dip of surface jointing, visible from a nearby road cut, were considered, it was evident that the lower part of the air-drilled hole had encountered this fracture. Analysis of the footage data substantiate this conclusion because the penetration rate nearly doubled below 20 feet in the air hole, but was nearly constant in the mist hole. Drilling time from 10 to 20 feet was 25.5 and 27.5 minutes with air and mist, respectively, but was 14.5 and 26.5 minutes, respectively, from 20 to 30 feet. Considering only the data from 10 to 20 feet as reliable, the decrease in penetration rate was 7.8 percent owing to mist drilling.

The Moenkopi core data show a uniform sandstone matrix (except for the fracture which was partly filled with crystals) with average characteristics of 8.9 percent porosity, 5.5 md permeability and 6,900 psi compressive strength. Figure 3 shows the drilling rate curves from 10 to 20 feet.

## Kaibab Limestone Test

The fourth and last drill site was in the Kaibab Limestone about 15 miles south of Winslow, Arizona. The holes were drilled with 10,000 lb of bit weight at 56 rpm. For the 16-foot interval from 4 to 20 feet, the drilling time was 28.5 minutes with air and 33.0 minutes with mist. This reflects a 15.8 percent reduction in drilling rate due to the injection of soapy water.

A 10-foot core taken from 8 to 18 feet showed that the drilled section was not a homogeneous formation. It graded from a vugular limestone at the top to a sandy lime in the middle and a limy sand at the bottom. As a result the average rock characteristics are of minor significance. The porosity ranged from 13.8 to 21.5 percent for an average of 18.5 percent. Permeability ranged from 2.3 md. to 90.6 md, and the average of six sample points was 46.8 md. Compressive strength was 8,800 psi in the limestone, but dropped to 2,900 psi in the limy sand at the bottom of the core. The data are presented in table 1. The drilling rate curves are shown in figure 4. Drilling rate data for all four locations are presented in table 2.

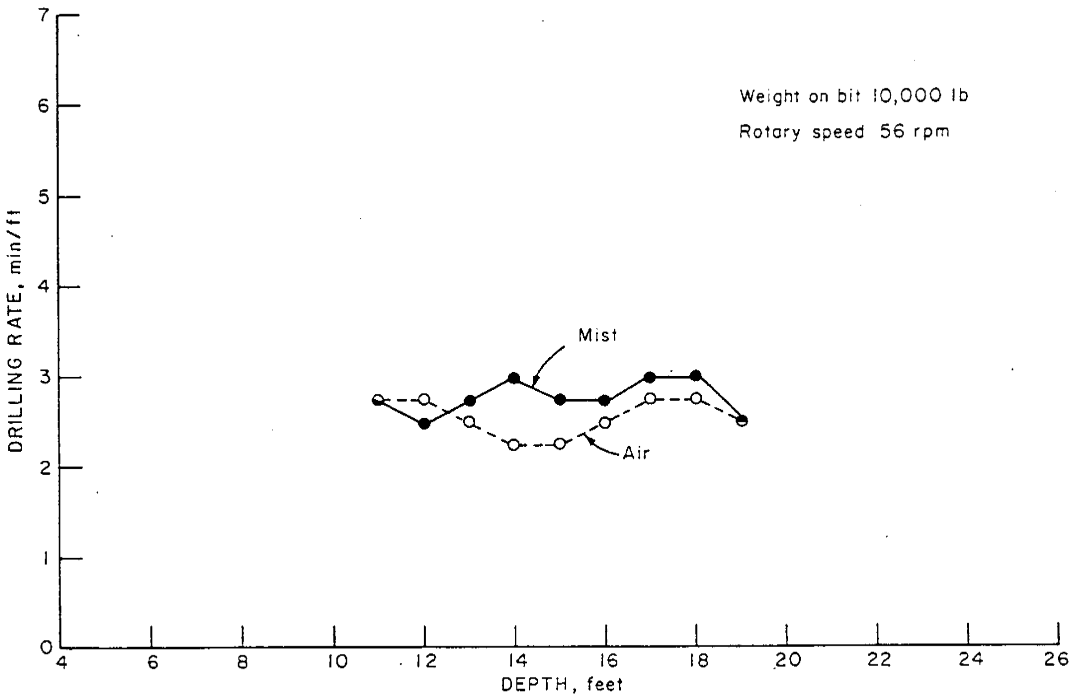


FIGURE 3.-Drilling Rate vs. Depth, Moenkopi Sandstone.

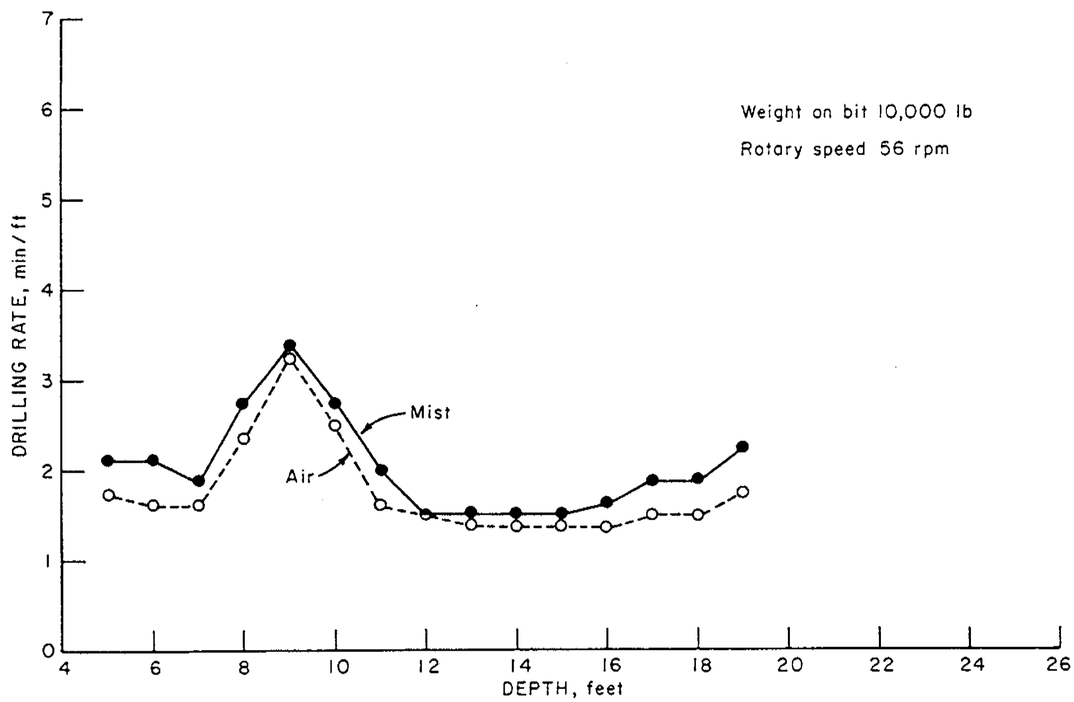


FIGURE 4.-Drilling Rate vs. Depth, Kaibab Limestone.

TABLE 2. - Drilling data tabulation: air-mist penetration rate experiment

| Formation | Overall depth interval, feet | Length of compared interval, feet | Air drilling time, minutes | Mist drilling time, minutes | Change compared with air, percent | Penetration rate, ft/hr | |
|---|---|---|---|---|---|---|---|
| | | | | | | Air | Mist |
| Coconino Sandstone... | 9-28 | [1] 16 | 61.5 | 69.0 | -12.2 | 15.6 | 13.91 |
| Claystone... | 8-30 | [2] 21 | 41.5 | 42.0 | - 1.2 | 30.4 | 30.0 |
| Moenkopi Sandstone... | 10-20 | 10 | 25.5 | 27.5 | - 7.8 | 23.5 | 21.8 |
| Kaibab Limestone... | 4-20 | 16 | 28.5 | 33.0 | -15.8 | 33.7 | 29.1 |
| Average change | | | | | - 9.3 | | |

[1] 3 ft deleted, parameter control inaccurate.
[2] 1 ft deleted, parameter control inaccurate.

Note 1. Negative sign indicates that mist drilling was slower than air drilling.

Note 2. Individual footage data were taken during the experiment but are not presented because an error of a few seconds or inches in depth on a per-foot measurement exceeds the magnitude of the percent change in drilling rate but has little effect on the data for the overall interval.

## CONCLUSIONS

Evaluation of this experimental field data has led to the following conclusions regarding penetration rate changes when air drilling is converted to mist drilling.

1. This work confirms the previous speculations that the addition of soapy water causes a loss of penetration rate when air drilling is changed to mist drilling at shallow depths.

2. The penetration rate loss due to the physical action of the soapy water spraying through the bit is of low magnitude, and for shallow, hard surface formations it is probably in the range of 12 percent compared to air drilling rates.

3. Further investigation is probably justified toward development of a downhole liquid separator with a ported sub which would inject the soapy water above the bit while mist drilling.

4. Mist could be used for dust control in shallow, soft-surface drilling with only a small loss of penetration rate.

## ACKNOWLEDGMENTS

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