UNCONVENTIONAL TECHNIQUES APPLIED TO AIR DRILLING OPERATIONS

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INTRODUCTION

Air drilling is utilized in various areas because of the improved penetration rate when compared to conventional mud drilling. When utilized in combination with conventional logging techniques, it improves the evaluation for both exploratory and development wells. However, its application is limited when coring or directional drilling is required since both of these operations are normally completed with mud in the hole.

In two recent exploratory drilling programs Shell successfully air-cored the objective formations and successfully operated the Dynadrill with air and air-mist to sidetrack a well and to make directional corrections. The decision to complete these operations with air rather than mud was due, in each case, to an estimated three to four-fold improvement in penetration rate and to obtain a better evaluation of any gas shows when drilling the remaining footage to total depth with air versus clear brine or mud. Although the individual operations using air are more expensive, when compared to the same operation using fluid, the overall economics of the drilling operation justify their use.

Use of these techniques in other air-drilled wells is a matter of economics and should be evaluated on each well. The purpose of this paper is to present Shell's experience for use by others in making their evaluation.

AIR CORING OPERATIONS

Dry air and air-mist have been used in six exploratory wells in the Appalachian Basin to core limestone formations in the depth range of 3000 to 7700 ft. The amount of coring in each well depended on the limestone formation thickness, reservoir rock quality encountered in the first core, and productivity characteristics of the rock. In actual operations the cored interval varied from 12 to 135 ft.

Since all wells involved in the air and air-mist coring operations were exploratory, the decision to core with air was strictly dependent on the safety of the operation and on hole conditions at core point. In initial wells, approximately 15 ft of the objective formation were drilled prior to picking up the coring assembly to determine if formation gas was present. If a gas flow was detected either prior to coring or during the air-coring operation, the well was to be loaded with mud and the coring operation resumed.

An 8-5/8 in. surface casing string of sufficient weight and grade was set in order to withstand maximum surface shutin pressure without fracturing the formation below the casing shoe. The surface casing design for these wells was based on normal design criteria for drilling exploratory wells and did provide a necessary safety precaution for attempting to air core.

The typical coring assembly included a 6-23/32 in. x 3-1/2 in. diamond corehead, a standard 5-3/4 in. x 3-1/2 in. core barrel stabilized near the bit and a circulating control sub and jars every 30 ft. The normal operating procedure was to cut the first core with a 30-ft barrel. If additional core was warranted and if no problems were encountered on the first run, an additional 30-ft core barrel section was picked up for coring a 60-ft interval on successive runs. The 6-23/32 in. core hole size was reamed out as required to the original 7-7/8 in. hole size. The typical operating parameters were as follows: bit weight 5-30,000 lb, rotary speed 30 to 40 rpm, and an air circulating volume of 1200 CFM. Table 1 summarizes the performance of the air and air-mist coring operations and shows data for mud coring in similar formations.

TABLE 1—PERFORMANCE OF AIR AND AIR MIST CORING

WELL	BIT NO.	INTERVAL CORED	FOOTAGE CORED/ RECOVERED	PENETRATION RATE	BIT WEIGHT	ROTARY SPEED	FLUID USED	FORMATION DESCRIPTION
A	1	4376-4395′	19/19′	8.4′/hr.	10,000 lbs	28 rpm	air	Limestone and interbedded shale
		4395-4398′	3′/1′	0.7′ ″	10,000 ″	28 ″	mist	Shale and sandstone
	2	4398-4399′	1′/0′	0.4′ ″	10,000 ″	28 ″	mud	Sandstone
B	2	4240-4259′	19′/18′	2.9′ ″	14,000 ″	32 ″	air	Shaly limestone
C	3	6531-6561′	30′/30′	6.3′ ″	7,000 ″	30 ″	air	Shale and shaly limestone
		6561-6603′	42′/38′	6.4′ ″	5,000	30 ″	air	Shaly limestone
		6603-6619′	16′/4′	6.4′ ″	5,000 ″	40 ″	air	″ ″
		7197-7202′	5′/5′	4.0′ ″	5,000 ″	40 ″	air	Silicious limestone
	4	7250-7277′	27′/14′	4.8′ ″	5,000 ″	40 ″	air	Limestone and silicious limestone
		7277-7292′	15′/6′					
D	5	6709-6739′	30′/30′	17.1′ ″	9,000 ″	40 ″	mist	Shale
		6947-6957′	10′/10′	4.0′ ″	9,000 ″	40 ″	mud	Shaly limestone, fractured
		6957-6967′	10′/10′	5.0′ ″	9,000 ″	40 ″	mud	″ ″ ″
		6967-6997′	30′/28′	6.0′ ″	5,000 ″	30 ″	mud	″ ″ ″
		6997-7011′	14′/14′	2.9′ ″	30,000 ″	30 ″	mud	″ ″ ″
E	6	7738-7750′	12′/12′	1.8′ ″	15,000 ″	40 ″	air	Silicious limestone, limestone and chert
F	7	3051-3081′	30′/30′	5.0′ ″	16,000 ″	30 ″	mist	Shaly limestone

Attempts to air and air-mist core all six wells were only partially successful. Two wells required loading the hole with mud to complete the coring operation. Both of these wells were air-mist coring when hole sloughing problems were encountered, probably due to wetting of the exposed shale. Barrel sticking was evident in these two wells, and coring operations were terminated.

Two major problems were encountered which have a great influence on the economics of air coring; barrel jamming and diamond corehead wear. Barrel jamming occurred in three wells, requiring frequent trips to core the required footage. Two of these wells were cored with dry air, and the third well was cored with mud. In the remaining three wells, all cored with air or air-mist, barrel jamming was not evident. However, corehead wear was a problem in two of the three wells.

No definite conclusions were made regarding the barrel jamming tendencies of air versus mud coring, due to variations in the formations encountered. Although the mud-cored intervals showed a more severe barrel jamming problem, the fractured nature of the shaly limestone formation was probably the major cause of the difficulty. In the air-cored wells, there were no indications of fractured formations. However, core breakage was evident along thin interbedded shale planes. The data suggest that barrel jamming tendencies with air and air-mist coring are prevalent. Only three of eight runs with a 30-ft barrel were successful in coring the entire 30 ft. The average footage cored per run was 21 ft.

Diamond corehead wear was the second problem encountered when coring with air or air-mist. The maximum footage cored with a single corehead was 93 ft, with an average footage of 35 ft per bit. Diamond usage ranged from 30-70% of the total diamond carat weight (average 48%). Based on the coring rates and a description of the recovered cores, most of the diamond usage appeared to be due to a highly abrasive silicious section encountered while coring. No major advantages could be detected utilizing fluid versus air. The same quartz sandstone section which damaged two bits while air coring could not be satisfactorily cored utilizing mud. Because of the variations in the formations cored, no predictions were possible as to the differences in corehead life with air, air-mist or fluid in similar formations.

Core recovery with air and air-mist was 207 ft of the 249 ft cut, 83%. Core recovery for the 65 ft of formation cored with mud was 97%.

Although barrel jamming and corehead wear problems were costly, an average savings of $14,000 per well was realized in the four wells where the coring operation was completed with air or air-mist. The cost savings were due to the improved penetration rate with air below the cored interval.

DYNADRILL OPERATIONS WITH AIR

Dynadrill operations with dry air and air-mist were successfully completed in two exploratory wells. The first well, located in the Black Warrior Basin, was air drilled to a depth of 10,200 ft before encountering a major fishing job. Following unsuccessful attempts to recover the fish, the well was plugged back to a depth of 5100 ft and sidetracked utilizing a 6-1/2 in. Dynadrill operated with dry air. The second well, located in the Appalachian Basin, was air-mist drilling when it became necessary to drop hole angle and/or change drift direction to hit a specified target. Initial attempts to sufficiently drop hole angle by reducing bit weight and changing bottomhole assemblies were unsuccessful. After attempts failed to correct drift direction with a 6-1/2 in. motor, a 5-in. Dynadrill operated with air-mist was used to turn the well. The operating parameters and performance of the different motors used are summarized in Table 2.

TABLE 2—DYNADRILL OPERATING DATA

Dynadrill Size, in.	Circulating Fluid	Interval, ft	Footage Drilled, ft	Penetration Rate, ft/hr
5	Air-mist	5413-5477	64	21
5	Air-mist	5477-5588	108	27
5	Air-mist	5779-5828	49	19
6-1/2	Air	5098-5144	46	13
6-1/2	Air-mist	Surface test	-	-
6-1/2	Air-mist	Surface test	-	-

Dynadrill Size, in.	Surface Oper. Conditions Pressure (psi)	Volume CFM In.	Bit Size, in.	Bit Type	Bit Condition	Weight On Bit, lb.
5	240	1200	7-7/8	millcutter	T4-B5-I	2000
5	240	1200	7-7/8	millcutter	T4-B6-I	2000
5	240	1200	7-7/8	millcutter	T3-B4-I	2000
6-1/2	Not reptd.	1800	9-7/8	millcutter	T2-B2-I	3000
6-1/2	150	1200	-	-	-	-
6-1/2	200	1200	-	-	-	-

In the first well, the hole was sidetracked in a Pennsylvanian shale section using a 9-7/8 in. millcutter bit on a 6-1/2 in. Dynadrill. Later, the hole was reamed out to the original hole size of 12-1/4 in. The down hole motor was operated with dry air for a total of 3-1/2 hrs and made 46 ft of new hole. A misture of oil and graphite was injected into the dry air stream at a rate of one ppm with a chemical pump in an attempt to provide the necessary lubrication. The oil-graphite lubricant was used instead of the recommended dry graphite because a suitable graphite injector was not available.

In the second well, the hole was directionally turned in a Devonian shale section, operating the motor with air-mist. The injected soap solution, 8 bbl per hr total liquid, was considered satisfactory to provide the necessary lubrication to operate the motor. The same 5-in. motor was operated in three runs using 7-7/8 in. millcutter bits to make the directional correction. Because of a concern for bit integrity, the motor was operated for a short period, three to four hours, then pulled and the bit changed. The 5-in. motor operated satisfactorily, drilling 221 ft of new hole in 9-1/2 hrs.

One problem was encountered due to the uphole water flow. The time involved in unloading the hole on the initial run and the two successive runs, with the Dynadrill on bottom, was up to five hours. Normally, this operation would take one to two hours. While the well was unloading, the motor operated intermittently.

Although the downhole motors operated successfully and the desired results were achieved in both wells, the 6-1/2 in. motor, operated with dry air and the oil-graphite mixture for lubrication, sustained damage. The rubber motor stator assembly required replacement. The cause of this damage was undetermined. It may have been due to frictional heating or excessive operating speed when running the motor off bottom. No damage was detected in either the 5-in. or 6-1/2 in. Dynadrills operated with air-mist.

Air volume requirements necessary to operate the downhole motors were within the capacity of the compressors and booster compressor normally required to air drill the well. Both the 5-in. and 6-1/2 in. Dynadrills were successfully operated on bottom, with air circulating volumes of 1200 and 2000 CFM, respectively. The air volume used measured in CFM, is approximately equal to 5.5 times the recommended liquid circulating rate measured in gpm. Two different 6-1/2 in. motors failed to operate near bottom even though during surface tests the motors appeared to run satisfactorily. In this case the air circulating volume was 1200 CFM, which is equivalent to an air-to-liquid ratio of 3.7 CFM per gpm. Dynadrill's published rule of thumb for the air volume necessary to operate the motor is 4.5 times the recommended liquid circulating rate. Air pressure required to operate the motors was within the range of normal compressor and booster compressor ratings.

Operation of the Dynadrills with air and air-mist allowed the drilling of an additional 7500 ft of hole with air and air-mist in the two wells. The resulting savings generated from both operations was $65,000.

SUMMARY

These field tests demonstrate the ability to utilize air for coring and operation of the Dynadrill. Although problems were encountered, particularly in the air-coring operations, the savings from maintaining the ability to drill the remaining footage of hole with air more than compensated for these problems. Future application of these techniques should depend on the safety of the operation, appraisal of the potential for success and the estimated economic rewards.

BIBLIOGRAPHY

1. "Dyna-Drill Handbook," First Edition, Copyright 1970.