SAND--8[illegible]1634C

CONF-811023--1

INVESTIGATION OF PERCUSSION DRILLS
FOR GEOTHERMAL APPLICATIONS

SAND81-1634C

John T. Finger

ABSTRACT

A series of tests was conducted to provide data for an economic evaluation of percussion drilling in geothermal reservoirs. Penetration rate, operation on aqueous foam, and high temperature vulnerabilities of downhole percussion tools are described.

INTRODUCTION

Part of Sandia's program management in Geothermal Drilling and Completions is an attempt to identify advanced drilling systems that could drastically reduce well costs. One of the candidate systems to be evaluated is percussion drilling, which has the advantages:

- High penetration rate in brittle rock
- Light weight on bit for straighter holes
- Ability to use low density fluids

The general method of evaluating a system is to quantify its changes in performance and equipment requirements compared to a standard model and then to examine the effect of those changes on well cost.[1]

The term "percussion drilling," especially in the minind g industry, sometimes means a technique that uses a stationary pneumatic or hydraulic drive unit to transmit rotation, static thrust, and cyclic impact to the bit through a long shaft called the drill steel. The work described in this paper concerns only downhole motors that

MGW

DISCLAIMER

use the drilling fluid to drive a reciprotating piston against a bit or bit sub.

The results of this investigation are in four parts: 1) comparison of penetration rates of different tools in uniform rock samples 2) demonstration that hammers can operate at high temperature 3) demonstration that hammers can operate with stable aqueous foam as a drilling fluid 4) identification of other problems that constrain percussion's use in geothermal drilling. Each of these parts is described in detail.

Penetration Rate Comparison

All tests of penetration rate (PR) were done in Sierra White granite, a rock representative of the Roosevelt Hot Springs, Utah geothermal area. This is a fairly strong granodiorite that has an unconfined compressive strength of 28,200 psi, porosity $\leq$ 1%, and quartz content of about 25%.[2] The tests were done at Drilling REsearch Laboratory, Salt Lake City, Utah, using a drill rig instrumented to measure bit weight, torque, rotary speed, penetration, drilling fluid flow rate and pressure, and temperature at several points in the test item. All holes drilled were approximately 8" diameter. The baseline for PR comparisons was a set of data for a 7 7/8", tungsten carbide insert, roller cone mining bit operated over a range of bit weights from 10,000 to 40,000 pounds and a range of rotary speeds from 40 to 100 RPM. (Fig. 1). Although this unsealed roller bearing bit could be run at higher bit weights and rotary speeds, the values chosen realistically represent field practice.

Penetration rates were measured for two basic types of percussion tools--those with roller bits and those with solid head bits. The hammers which used the roller bit from the baseline tests are commonly called "oilfield" hammers and are rented, not bought, from service companies. The hammers which use solid bits with hemispherical tungsten carbide inserts are called mining or industrial hammers and are usually bought from one of the several manufacturers.

Since the bits imposed different constraints on the tools, the two types were tested with different variables. The oilfield tools were operated at a constant rotary speed with varying bit weight and fluid supply pressure. These results, shown in Fig. 2, demonstrate that the PR is relatively insensitive to bit weight and strongly influenced by supply pressure. This is reasonable, since 1) the changes in bit weight are small compared to the force of the hammer blows and 2) it has been shown theoretically[3] that power input to the rock should increase as the 3/2 power of the fluid supply pressure. Three tools were tested with the roller-cone bit--two rental air-powered hammers and a prototype liquid-powered hammer. The latter tool was designed, built, and field tested by Pan American Petroleum Corporation (now Amoco Production Research Center), but was never built commercially because of the unfavorable economics.[4] It has been operated with drilling mud as the driving fluid, but in these lab tests clear water was used.

In general, the performance is about the same for the air tools and the liquid tool, but the costs of using them may be quite different. The incompressible mud requires a valve design for the liquid tool that is more complex, more expensive, and shorter lived than the equivalent valve in the air tool. The air tool, however, may require a higher pressure compressor than a normal air-drilled well while the liquid hammer driving pressure is more likely to be within the capacity of a normal mud system. The air hammer doesn't increase the flow rate requirements, since more air is needed to raise cuttings than to drive the hammer, but the extra pressure drop may require a booster on the compressor.

Comparison of Figures 1 and 2 shows that conventional drilling with high bit weight and rotary speed can give PR as great as with hammer assist, but these high values are not always possible because of shallow depths that limit string weight or because of faulted formations that give crooked hole problems. It is also useful to consider the torques and axial forces imposed on the drill string. Table I shows that, for equal penetration rates, these loads are lower when using hammers. Although the competent rock and the short stiff drill string in the laboratory gave larger variations in torque for the hammer than for the unaided bit, the lighter bit weights and cyclic impact of the hammer should reduce bit sticking in faulted formations, thus lessening the chance of a twist-off.

The tungsten carbide buttons used in the industrial hammers can't withstand the large shear loads that would be imposed by rotating under high bit weights, so these tools were operated at a constant bit weight and varying supply pressure and rotary speed. These results, shown in Fig. 3, again confirm that PR is highly dependent on air pressure. The effect of changing rotary speed is not consistent, however, since an increase in speed may increase or decrease the penetration rate. All of the reasons for this effect are not clear, but it is primarily an effect of the angular displacement of the buttons between blows. For a given blow frequency, which is determined by supply pressure, there should be an optimum rotary speed that will place the buttons over fresh rock for each blow. In the field, the bit wear is minimized by choosing the lowest rotary speed that will give an acceptable drilling rate.

Comparison of Figures 2 and 3 shows that the industrial hammers, with less weight on bit and about the same air supply, drill much faster than the oilfield hammers. There are two major reasons for this: 1) the oilfield hammers are designed with lower piston impact velocities to protect the bearings in the roller bits and 2) the energy transfer through the one piece industrial bit is more efficient than through the bearings and threaded joints in the roller bit.

To examine the effect of rock temperature on percussion drilling performance, tests of small percussion drills were conducted in granite heated to 350°F and to 500°F.[6] Results related to driving pressure and rock temperature were:

Temperature Air Pressure	Ambient 100 psi	350°F 110 psi	500°F 110 psi
Average PR, ft/hr	54.8	73.6	80.0

This is encouraging for geothermal applications, although part of the increased PR may be due to thermal stresses (introduced by laboratory heating) that would not be present in natural formations.

The principal conclusion of this comparison is that percussion drilling offers the possibility of significantly increased drilling rates in rock characteristic of many geothermal resources.

High Temperature Operation

Hammers are not normally designed to operate in the hot environment of geothermal formations, so commercially supplied tools are vulnerable at several points to high temperature. The O-rings and other seals are made of elastomers that will fail above about 300°F, and the valve tubes that control the air flow to the reciprocating piston are made or mounted with plastics that have similar high temperature behavior. To evaluate the performance of off-the-shelf tools, two industrial hammers were operated in an insulated shroud that was heated by passing the air compressor output through a gas-fired heat exchanger and then through the tool. The air temperature at the tool inlet was brought up to 350°F over a one hour period, with the bit raised off the cast-iron target to prevent hammer operation. Each tool failed about 3 minutes after hammering began, and each failed at the valve tube which controls piston movement. The static seals (O-rings) were not visibly degraded, but even their complete failure would only have caused a loss of efficiency, not stoppage of the hammer.

One of the hammers was retested with an aluminum valve tube. It ran for 52 minutes but again failed at the tube, almost certainly because of fatigue induced by a tool mark left when machining the tube. Again, there was no apparent degradation of the static seals.

Since the resilience of the tube material seemed to be important in avoiding fatigue, a polyimide plastic (DuPont Vespel) was selected for further testing. It has higher strength at 500°F than the standard material at room temperature, but is also stiffer. For this phase of the testing, the O-rings and the compression pad used to keep the hammer's internal assembly tight were replaced with silicone rubber duplicates. The standard test procedure was used again, and the hammer operated for four hours at 350°F before stopping. When it was cooled and disassembled, considerable debris was found in the top of the air distribution manifold. Metal agitators from a foam generator and chunks of rigid insulation from the high temperature air swivel had come through the air line and small particles of them had jammed the piston in the outer housing. The valve tube was slightly loose in the bit shank, but it had not suffered any degradation from the heat. The piston was driven out of the housing and both parts were inspected for gouges. Some small scratches were polished out and the tool was reassembled into the test stand. The air was brought up to 400°F and testing resumed. After nine more hours of continuous operation the hammer was running well, but the cast iron billet was drilled through. The test setup was cooled to ambient temperature and a new billet was installed. After two more hours of drilling, this time at 450°F, the hammer stopped again and was disassembled to find the valve tube crushed. The failure mode was different this time though, because the Vespel showed no sign of the melting or softening characteristic of the standard material. Measuring the pieces of the tube and the recess in the bit shank that holds the tube in place showed that the retaining rim in the bit had worn away and let the tube fall out to be smashed by the piston (Fig. 4). The tube, which showed no measurable wear, was made of an unfilled plastic and it is likely that the bit rim was abrasively worn by powdered insulation from the debris earlier found in the air manifold. Microscopic examination of the tube fragments showed particles of the insulation, which is 59% alumina and 33% silica, imbedded in the plastic.

Since the valve tube failure was not related to the high temperature, and since the silicone O-rings and compression pad were in good condition after the test, the principal conclusion of this phase of the testing is that commercial hammers with minor modifications can be operated at geothermal temperatures.

Hammer Operation on Foam

All of the commercially available tools that we tested are designed to be powered by compressed air. Air drilling gives high PR in many cases, but it suffers disadvantages of large air compressor requirements and inability to handle much water inflow. Since, compared to air, stable foam gives greater lifting capacity at lower annulus velocity[5] it can mitigate both of these problems. To examine the performance of an industrial hammer with foam as the driving fluid, a foam generator was added to the test stand air supply line. The property normally used to characterize foam is its liquid volume fraction (LVF), defined as (volume of liquid/total volume gas + liquid). Maximum lifting capacity is usually in the range LVF = .02 - .10, so test flow rates were aimed at those values. All runs were made with 5000 pounds WOB and 8" diameter bits.

The expansion of the gas through the hammer means that the LVF of the fluid entering the tool is much higher than that at the exhaust. To reduce the change in LVF across the tool, the backpressure into which the foam exhausts was raised to about 100 psi, while the intake pressure was also raised to maintain the proper pressure drop. The hammer was operated over a range of flow rates and LVFs (Table 2) to give performance comparable to air at the same flow rates (although the foam viscosity required higher pressures). Since hammers frequently run with a bypass to provide more air for lifting cuttings, foam may provide adequate drilling performance with smaller flow requirements.

The major conclusion of this phase of the testing is that commercially available hammers will operate satisfactorily using stable aqueous foam that has much greater lifting capacity than air.

Other Problems

There are other factors which will affect the cost and feasibility of using percussion drilling in geothermal resources: two of the most important are weight control and gauge wear.

Because all hammers have a slip joint that opens to stop the piston cycle when the bit is lifted off bottom, a certain minimum weight must be applied to the tool to keep this joint closed while hammering. For the tool sizes and pressures used in these tests, that weight is about 2500 pounds. For the tools using roller bits the maximum weight is not critical (hammer manufacturers recommend 15,000-20,000 pounds), but the solid head bits are very vulnerable to excessive weight. The tungsten carbide buttons are quite strong in compression but not in shear, so they can withstand high impact loads of hammering but not torque caused by high static bit weight. High WOB also increases the rate of abrasive wear on the carbides. Manufacturers' recommendations for maximum weight on bits used in the tests were 5000-6000 pounds. Weight control within a 4000 pound range is feasible with the small hydraulic rigs that are frequently used for shallow drilling, but accurate control with rigs having mechanically braked drawworks is very difficult below about 3000 feet. The current rig shortage, which is especially acute for geothermal drilling, may encourage the use of these portable hydraulic units for drilling as deep as possible before a heavy duty rig is brought on site.

Gauge wear is not as critical in roller bits as in solid head bits because the solid bits can't be used to ream. This requires either separate reaming operations to maintain hole diameter or the use of bits with stepped decreasing diameters. The former increases the cost for tools and trips and the latter implies an accurate knowledge of the bit wear rate so that a bit program will produce the correct hole diameter at bottom. This knowledge does not appear to be available, since an extensive literature survey[6] pointed out the large number of variables in wear of tungsten carbide and the lack of consensus on the dominant wear mechanisms.

The importance of gauge wear in specifying the bit program is clear, and experience in the PR testing showed that not only can wear occur quickly but that it has a large effect on performance. For example, a hole drilled by the 7 7/8" roller bit was reamed for about one foot with an 8" solid bit, which was then left rotating (off bottom) in the hole while foam flow was established.

This abrasion, probably aggravated by the wet foam, left wear bands as much as .250 inch wide on some of the gauge carbides. These wear spots reduced the PR from 40 ft/hr to 3.5 ft/hr with the same air flow.

Tests at Colorado School of Mines[6] showed unmeasurably small wear on two 1.625" diameter button bits used to drill 121 feet in gneiss and 118 feet in granite (one bit in each rock). It is at least possible, then, that long intervals can be drilled with acceptable wear rates, but this does not accurately predict bit condition.

Compared to solid bits, roller bits use a much larger area of tungsten carbide to cut the hole diameter. Roller bits used with hammers have greater penetration per revolution than the same bit without percussion. These characteristics mean that gauge wear in roller bit/percussion drilling is no worse than in conventional rotary and is much less severe than in solid bit/percussion.

Conclusions

The tests described here indicate that it is feasible to operate hammers at geothermal temperatures. Percussion drilling with solid head bits offers the greatest performance increase compared to conventional rotary but has more severe technical obstacles than percussion with roller bits. An economic analysis will be used to focus technical development in the most promising direction.

FIGURES:

TABLES:

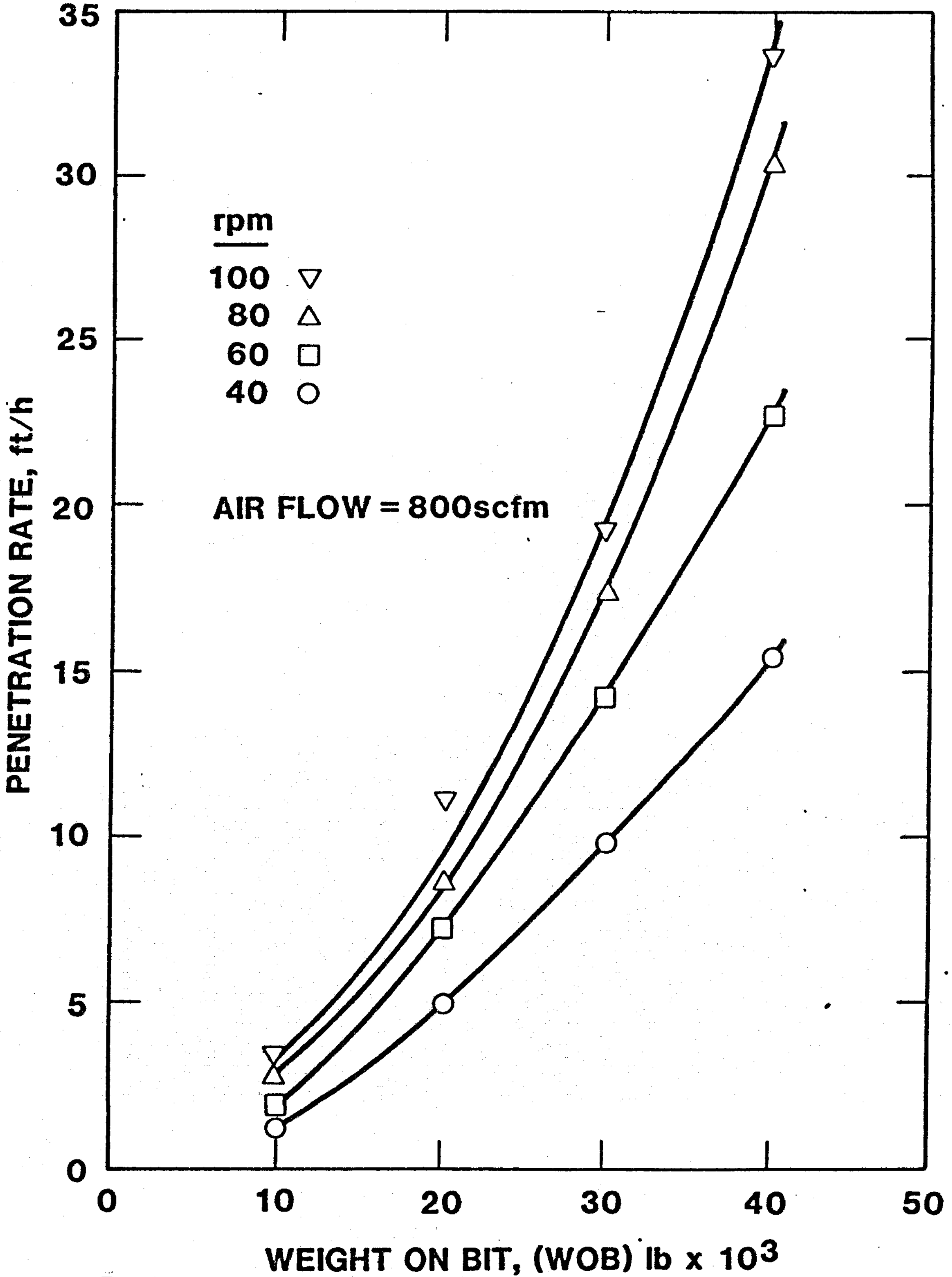

rpm
100 ▽
80 △
60 □
40 ○
AIR FLOW = 800scfm
PENETRATION RATE, ft/h
0
5
10
15
20
25
30
35
0
10
20
30
40
50
WEIGHT ON BIT, (WOB) lb x 10³

Figure 1

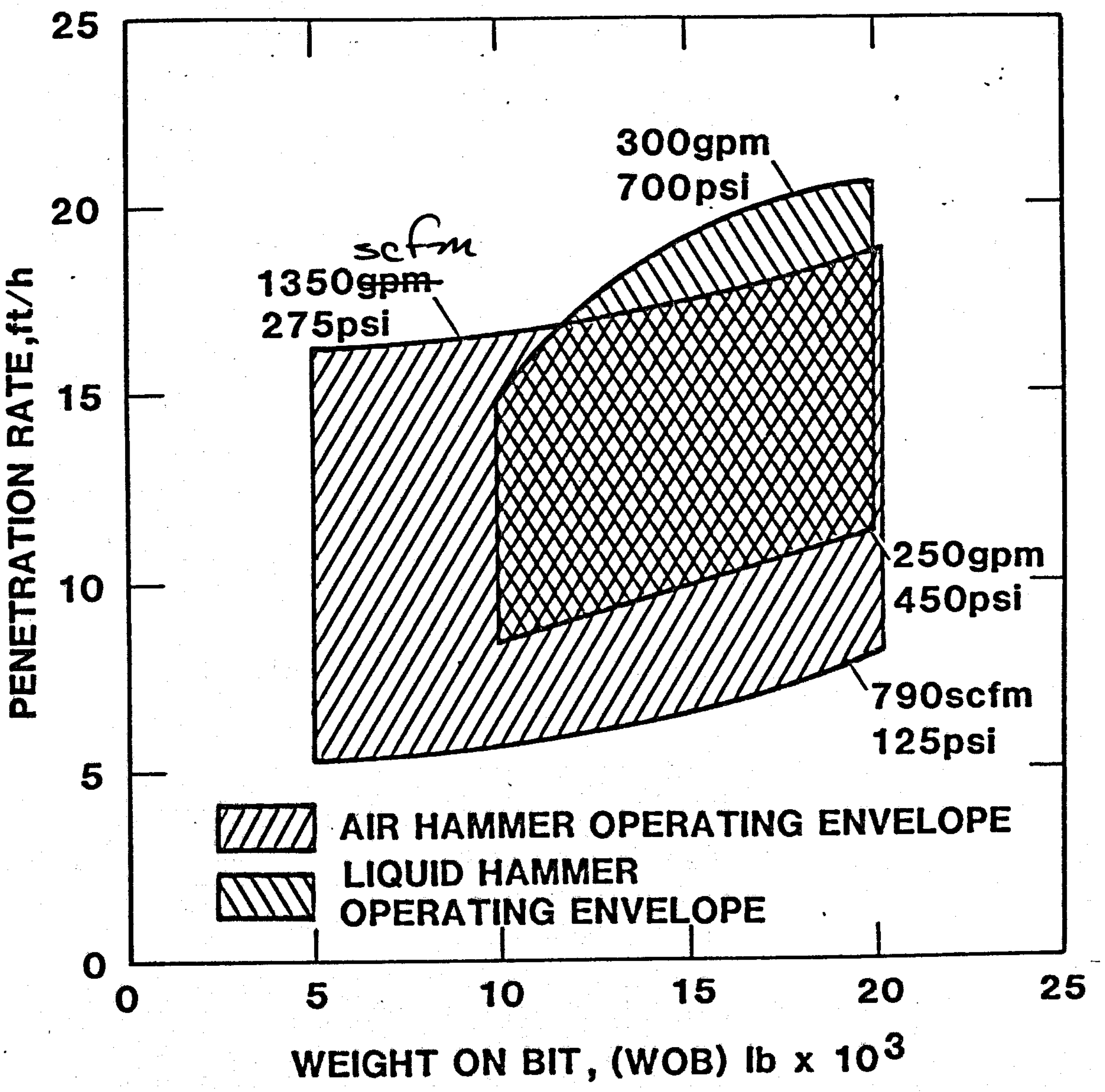
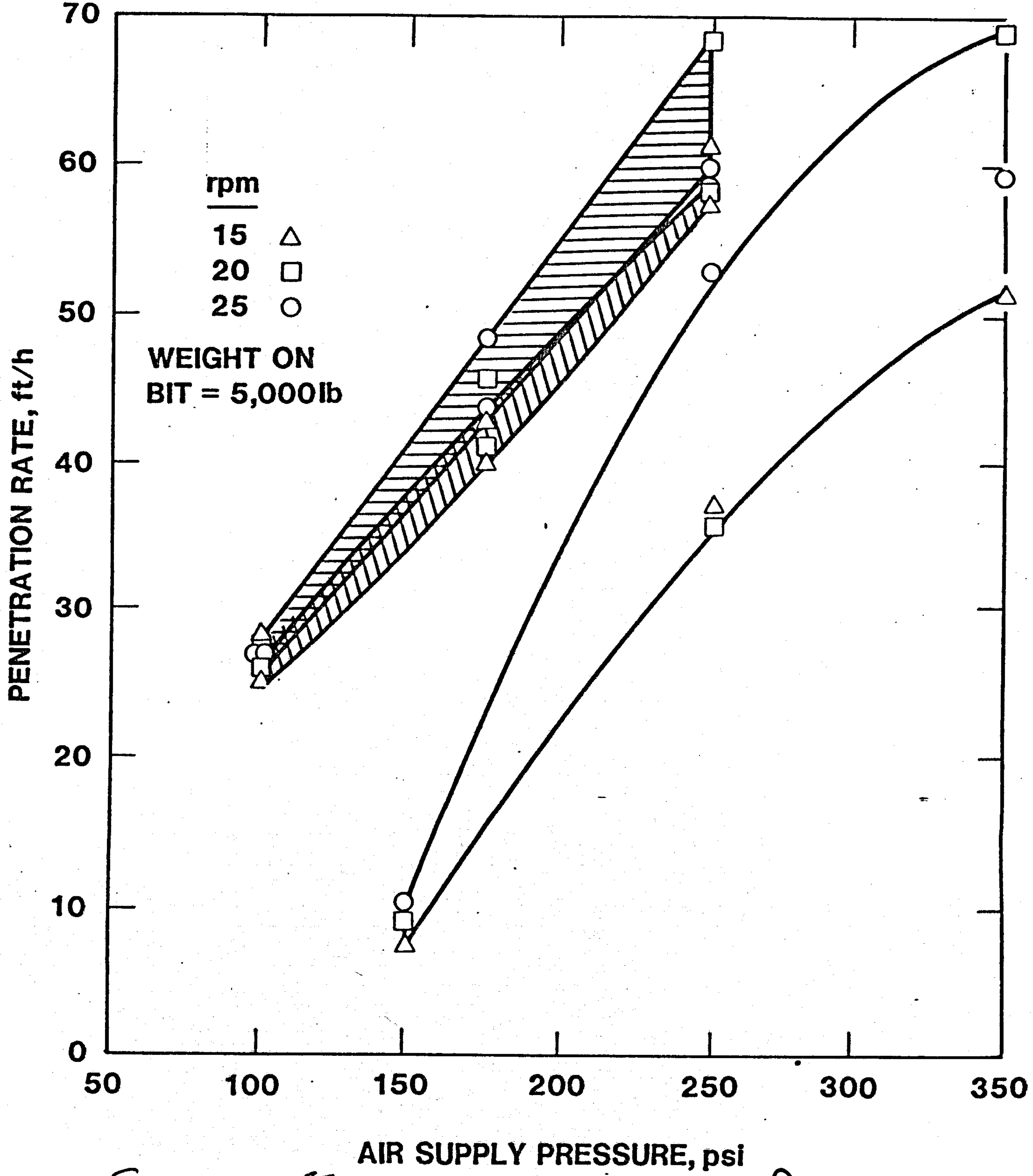

25
20
15
10
5
0
PENETRATION RATE, ft/h
300gpm
700psi
scfm
1350~~gpm~~
275psi
250gpm
450psi
790scfm
125psi
AIR HAMMER OPERATING ENVELOPE
LIQUID HAMMER OPERATING ENVELOPE
0
5
10
15
20
25
WEIGHT ON BIT, (WOB) lb x 10^3

FIGURE 2



~~Figure 3~~ (FLOW RATE ≈ 600 - 1100 scfm
FOR EACH HAMMER)

Figure 3

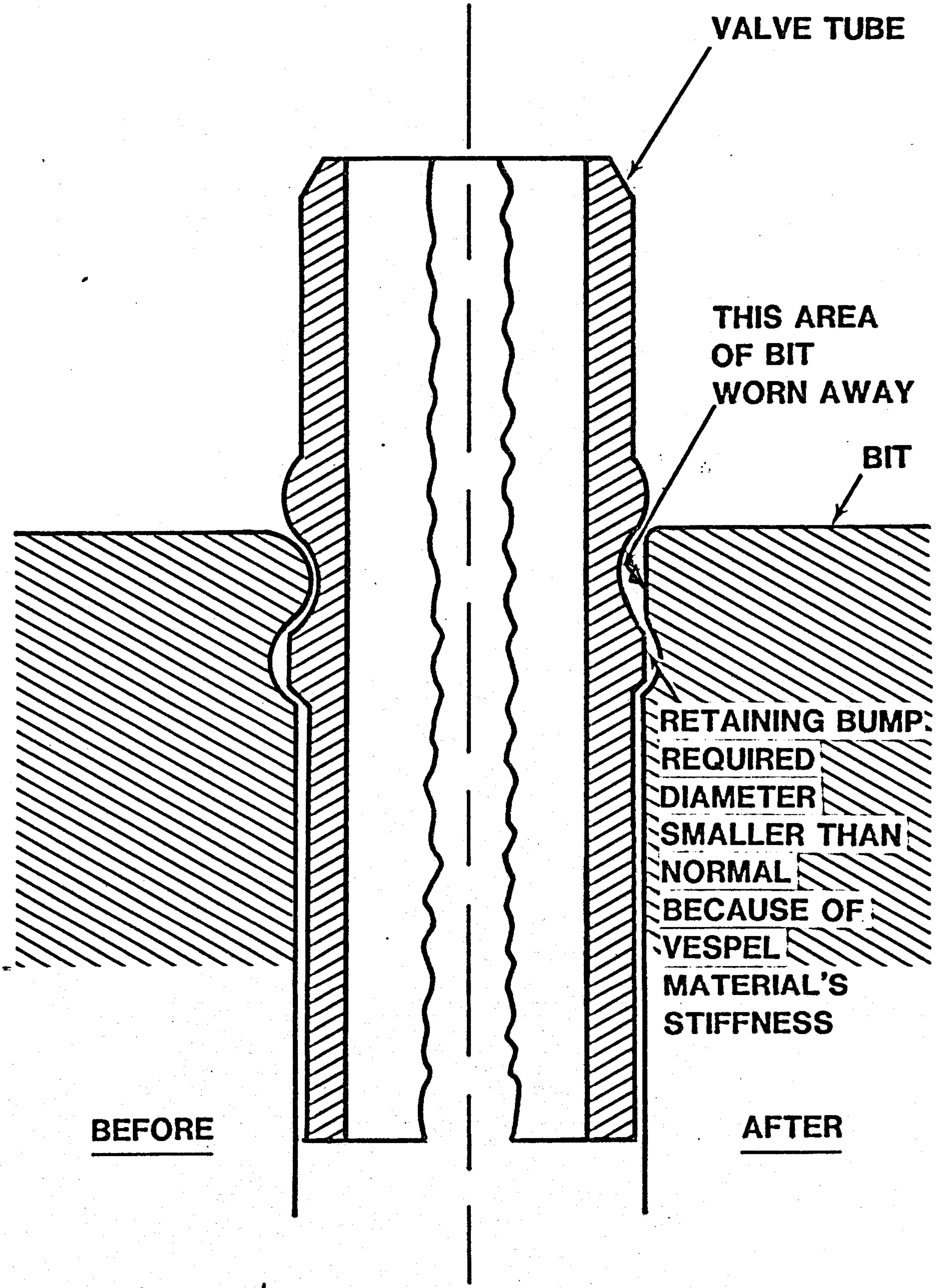

VALVE TUBE
THIS AREA OF BIT WORN AWAY
BIT
RETAINING BUMP: REQUIRED DIAMETER SMALLER THAN NORMAL BECAUSE OF VESPEL MATERIAL'S STIFFNESS
BEFORE
AFTER

Figure 4

TABLE 1

	Roller Bit	Roller Bit	Roller w/Hammer	Solid w/Hammer
Penetration Rate, ft/hr	18	18	18	26
Weight on Bit thousand pounds	30	40	15	5
Rotary Speed RPM	80	40	45	25
Axial Force, lb Average (Standard Deviation)	30,515 (4261)	39,491 (2864)	16,194 (7313)	4,898 (2836)
Torque, lb-ft Average (Standard Deviation)	882 (190)	1452 (269)	884 (258)	825 (193)

TABLE 2

RPM	Blow Freq., HZ	Air Flow scfm	Liquid* Flow, gpm	LVF at exhaust	Pressure, psi			ROP Ft/Hr
					Intake	Exhaust	ΔP	
15	13	750	0	0	210	30	180	40.0
15	--	950	20	.016	330	70	260	36.0
15	15.5	750	15	.019	310	90	220	21.3
25	15.5	750	15	.019	320	90	230	27.2
15	16.2	750	25	.029	340	80	260	32.7
25	16.0	750	25	.029	330	75	255	32.0
15	16.0	500	10	.022	340	105	235	20.7
25	15.2	500	10	.021	320	95	225	22.5
15	16.2	500	25	.048	340	90	250	24.6
25	16.0	500	25	.048	340	90	250	29.5
15	15.3	750	15	.016	290	75	215	24.0
15	16.6	750	32	.045	360	100	260	25.0
15	14.5	500	12	.019	260	70	190	23.0
15	16.2	500	28	.056	335	95	240	19.5
15	16.2	500	40	.084	375	100	275	24.5
15	11.3	300	9	.022	190	65	125	6.1
15	13.2	300	17.5	.050	235	80	155	5.0

*Liquid is a 2% solution of Thermofoam BW/D surfactant in water.

Nomenclature

PR - penetration rate - ft/hr

WOB - weight on bit - pounds

LVF - liquid volume fraction

REFERENCES:

1. Carson, C. C. and Lin, Y. T.: "Geothermal Well Costs and Their Sensitivities to Changes in Drilling and Completion Operations," Proceedings of the First International Conference on Geothermal Drilling and Completion Technology, Albuquerque, N.M., January 1981.

2. Pratt, H. R. and Black, A. D.: "Representative Geothermal Rocks," Drilling Research Laboratory, Salt Lake City, Utah, Report T80-08.

3. Clark, G. B.: Colorado School of Mines Quarterly, Vol. 74, No. 2, April 1979, p. 3.

4. Vincent, R. and Wilder, L. B.: "The Fluid Powered Percussion Drilling Tool," paper presented at the Seventh Annual Rotary Drilling Conference, Houston, Texas, February 1969.

5. Lorenz, H.: "Field Experience Pins Down Uses for Air Drilling Fluids," Oil and Gas Journal, May 12, 1980, p. 132.

6. Clark, G. B.: "Feasibility Tests of Properties and Wear of Tungsten-Carbide Percussive Rock Drill Bits at High Temperatures," Colorado School of Mines, Report to Sandia National Laboratories, Contract No. 62-7290.