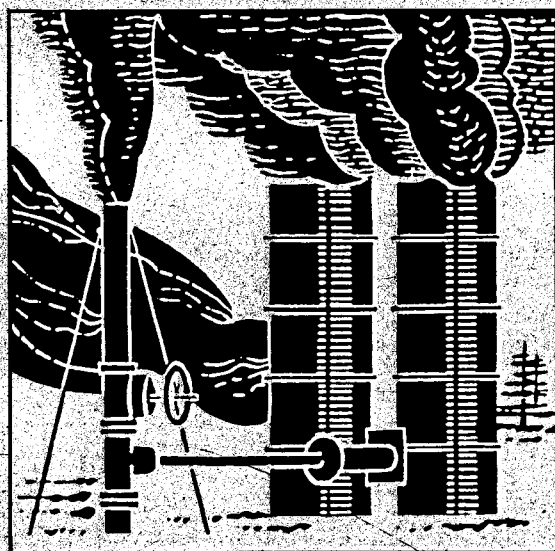


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PROGRESS TOWARD AN ADVANCED GEOTHERMAL DEEP-DRILLING SYSTEM

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SUMMARY - A previously developed concept for an advanced geothermal drilling system (AGDS) has been extended toward a feasibility design stage. Hardware projects for two percussion, air and hydraulic, hammer drills are underway. Two drillstring options and an unique nitrogen supply system are described.

1. INTRODUCTION

The basic concepts for an advanced geothermal drilling system (AGDS) were discussed previously (Rowley 1993). The proposed system is provided with elements that will increase bit life and penetration rate, and aid in solving the major drilling problems associated with high temperatures and lost circulation. The concept, Figure 1, has been extended further by studies of this purpose-developed system components (Rowley 1994; Rowley et al. 1994, 1995a, 1995b). A volunteer design team has been formed to review the project and to provide technical analyses, define needed design directions, and to direct the project toward a design feasibility stage.

The major elements and components of the concept have received preliminary design considerations and the two multiple flow path (dual-wall) drillstring options have been scoped, and an example of directions toward optimization of the inner, reverse mode circulation pipe size have been illustrated. A major investigation and search for appropriate percussion hammer drills, both hydraulic and air (nitrogen) driven, have been conducted. Only recently have such tool designs and developments been undertaken in the United States (Hall 1995; Bui 1995).

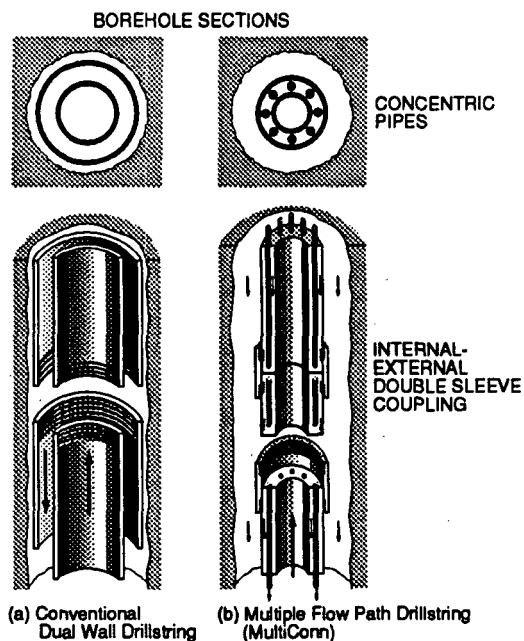
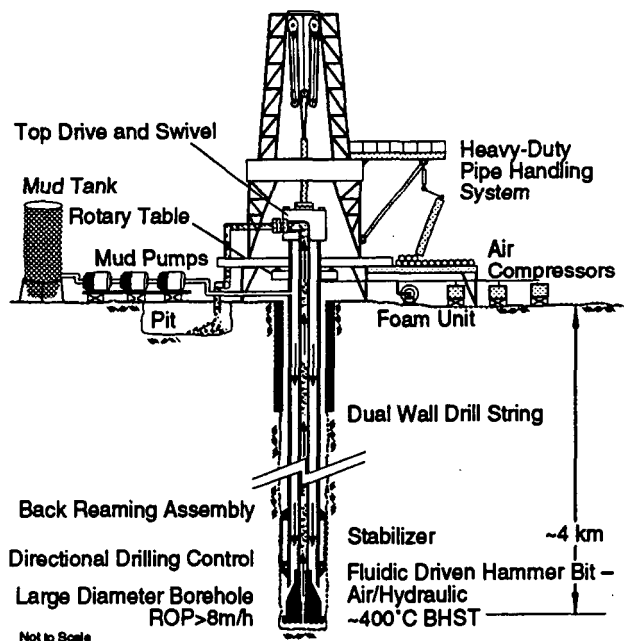


Fig. 1. Proposed advanced geothermal deep-drilling system concept.

Fig. 2. Reverse circulation drillstring options selected; (a) dual-wall, (b) multi flow path (MultiConn).

2. COMPONENT DETAILS

2.1 Drillstring Options

Figure 2 indicates the two configurations of the drillstrings under study; and Table 1 provides the major dimensions for these strings designed to drill a 311 mm (12-1/4 in) borehole to 4 km depth. It is suggested that use be made of drilling string connections or couplings based on the new Integral Joint Connections (IJC) premium casing designs (Klementich et al. 1993).

Table 1. Drillstring pipe sizes selected for study; (a) Dual-wall, (b) multi flow path.

(a) DUAL-WALL DRILLSTRING

Quantity	Outer Pipe	Inner Pipe
Outer Dia.: (in.)	9-5/8	7.0
Wall Thickness: (in.)	0.750	0.640
Unit Mass: (lb/ft)	71.8	44.0
Steel Area: (sq in.)	20.9	12.78

Total String Mass: $1.5 \times 10^6 \text{ lb}_m$

(b) MULTIPLE FLOW PATH DRILLSTRING

Quantity	Outer Pipe	Inner Pipe
Outer Dia.: (in.)	7-5/8	2-7/8
Wall Thickness: (in.)	0.500	0.360
Unit Mass: (lb/ft)	39.0	10.4
Steel Area: (sq in.)	11.19	3.20

Total String Mass: $6.5 \times 10^5 \text{ lb}_m$

Note: Hi Press Tubes are 1.0 in. OD Std, with 20 KSI Rating.

As an example of the type of analyses included within this study, Figure 3 shows the calculation results for the potential optimization of a dual-wall drillstring, with outer pipe diameter of 200 mm (9-5/8 in), for nitrogen (air) drilling. The dashed curves of bottom hole pressure vs flow rate indicate the flow necessary to lift cuttings and some inflow of

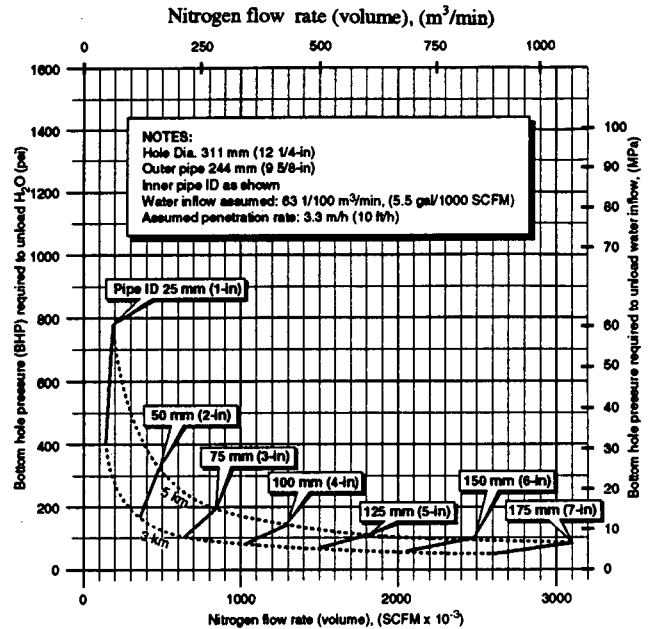


Fig. 3. Optimization analysis for dual-wall drillstring; nitrogen flow - pressure drop necessary to clean hole.

water and are parameterized for various inner pipe diameters. The trade-off of reduced pressure on the reservoir and flow volume (compressor capacity and cost) and the pressure requirements to clean and unload the hole are illustrated. It seems that an optimum diameter for the reverse circulation pipe ID is between 50 and 75 mm. Further analyses for these multi-flow-path strings should be undertaken, especially thermal and heat transfer simulations for the MultiCon system relative to cooling of BHA and provisions for special downhole sensors. Further study of use of treatment fluids in the annulus would be very desirable.

2.2 Percussion Hammer Drills

There have been innovative hammer development projects in Australia, Canada, China, Germany, Japan, Russia, and recently, two in the USA of interest for potential application to the AGDS design.

The two in the USA are illustrated in Figures 4 and 5. An air (nitrogen) tool (Bui 1995) has the valuable features of downhole indexing and can therefore be steered or "navigated".

Hydraulic hammers of new, innovative designs are under development by NOVATEK, Inc. (Pixton and

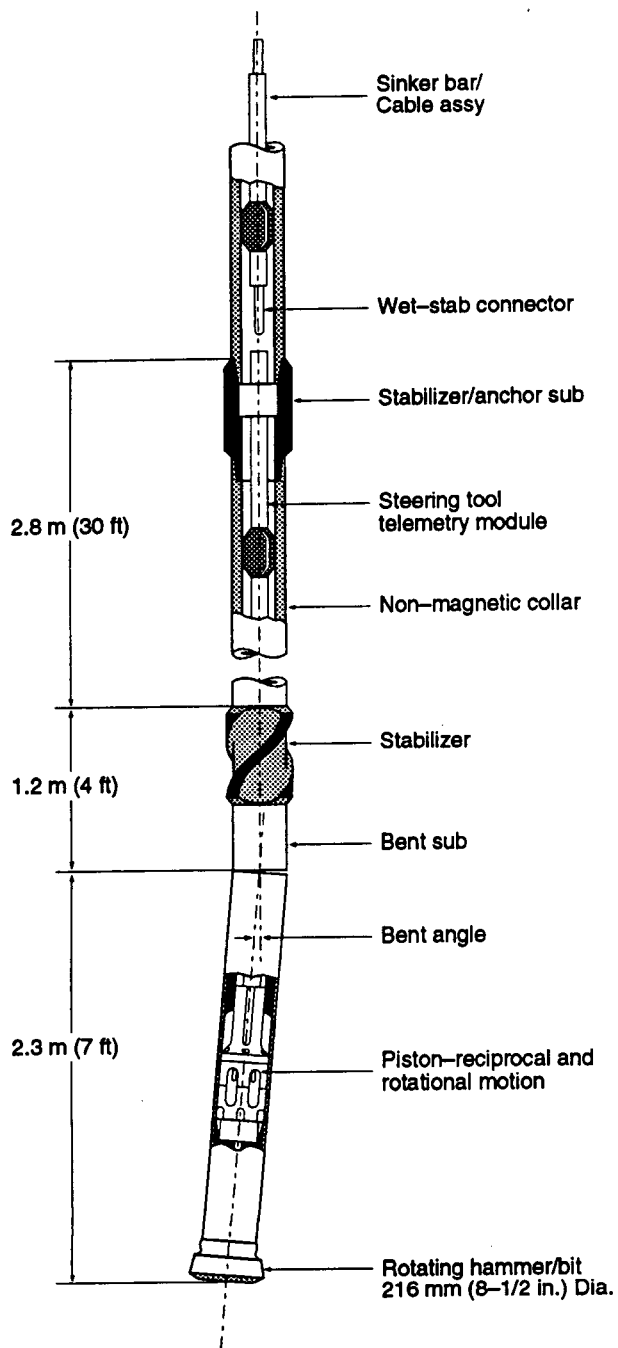


Fig. 4. Steerable percussion air hammer with downhole indexing (Smith Int'l., Inc.).

Hall 1995) with tools of 216 mm (8-1/2 in) and 311 mm (12-1/4 in), the latter specifically designed and developed for high-temperature, geothermal drilling applications; Figure 5.

Table 2 is a summary of the desirable features and the estimated performance characteristics for the AGDS hammer tools.

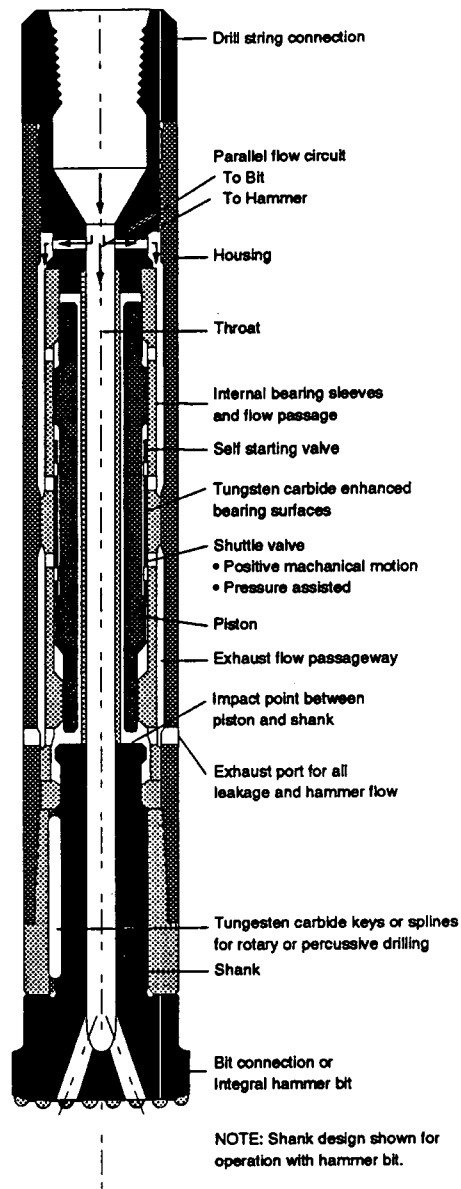


Fig. 5. Hydraulic geothermal hammer with parallel flow and high power features (Novatek Corp.).

Table 2. Hydraulic Percussion Hammer Specifications and Features.

HYDRAULIC PERCUSSION HAMMER
Design Goals & Preliminary Specifications (KTB)*

ITEM	APPROX. VALUE
Bit Dia.:	311 mm (12 1/4 in)
TCI (Cutter) Dia.:	10 to 12 mm
No. of TCI:	35
Stroke Energy:	2 to 4 KJ
Tool Length:	2 m
Tool Dia.:	197 mm
Tool Mass:	700 kg
Tool & Bit Life:	> 100 hours (MTBF)**

* Source: A. Sperber (1994)

** Mean Time Between Failures

DESIRABLE FEATURES OF

PERCUSSION HAMMER

- Air/Hydraulic Operation
- Variable Impact Frequency
- Parallel By-Pass Flow
- Self Starting Valve
- Anti-Clogging & Self-Cleaning
- Few Moving Parts
- No HT Seals
- Use with HEAVY Mud
- Operating Depth to 4 km
- 400°C Temperature Rating

2.3 Other BHA Components

The sketch in Figure 6 shows the conceptual design for the BHA proposed for the AGDS BHA. It will be necessary, for example, to have a thruster (often termed a "bumper sub") to control the force on the percussion tools. One such design concept is shown in Figure 7. This design needs to be developed for both hydraulic and air (nitrogen) service.

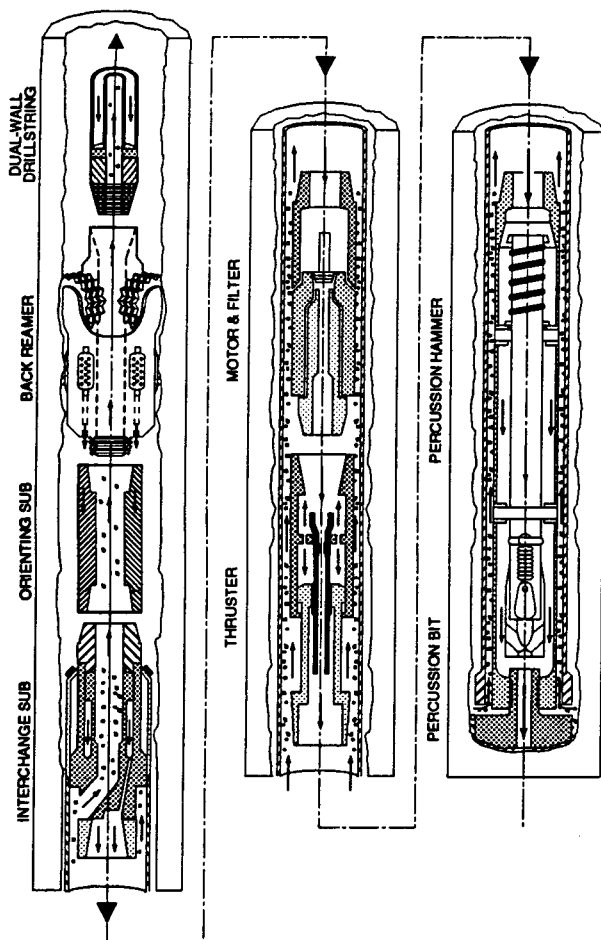


Fig. 6. Conceptual design for BHA elements.

2.4 Unique Nitrogen Source

The use of nitrogen, in place of air, has several advantages for geothermal drilling. The primary benefit is the great reduction in corrosion, very important if the goal of drilling 400°C reservoirs is to be effectively achieved. Figures 8 and 9 give the layout of a new nitrogen source, where the nitrogen is derived from the exhaust manifold of a diesel engine. Figure 9 gives the performance of several models of this source (Baugh 1994).

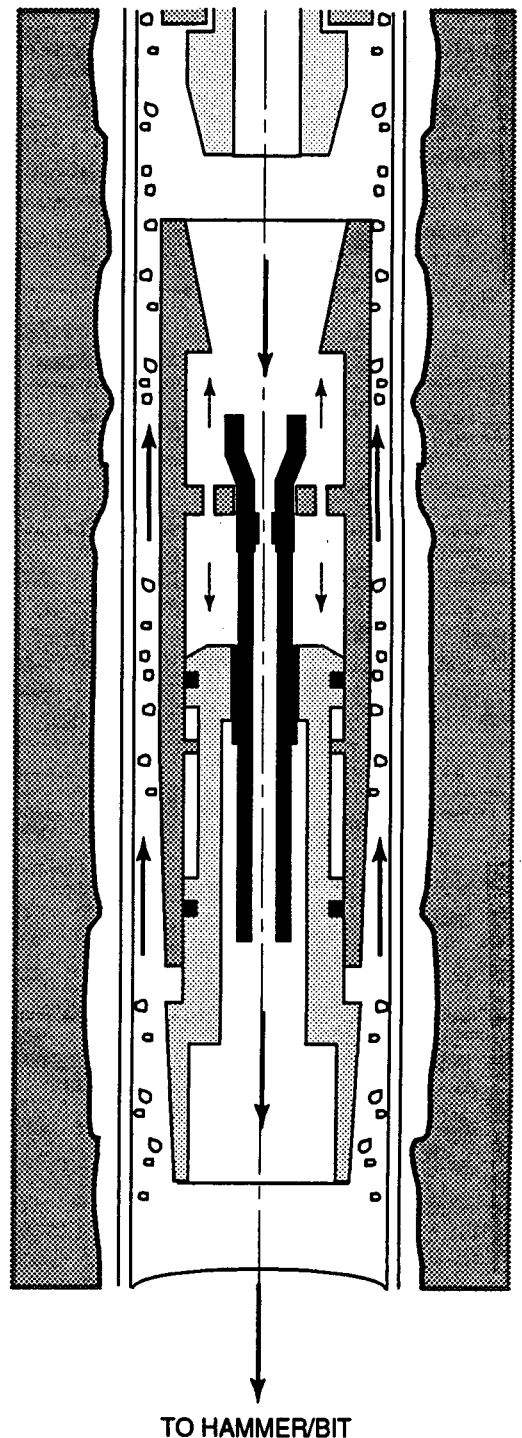


Fig. 7. Conceptual design of thruster.

3. CONCLUSIONS

The past two years have seen the formation of a 'design team' that has provided serious critique, input, literature, and many helpful contacts. The concepts for the AGDS system have progressed to a more mature state, and is on the verge of a feasibility design. Commercial sources for some of the elements suitable to be applied and research and development projects, for the needed percussion hammers especially, are underway.

The potential sponsors for any further AGDS development have as yet not been identified. But it seems that a continued volunteer effort might offer progress that can be of interest to potential funding sources. Perhaps an evaluation of the various subcomponents can be sustained as they each might have more immediate use in current drilling projects.

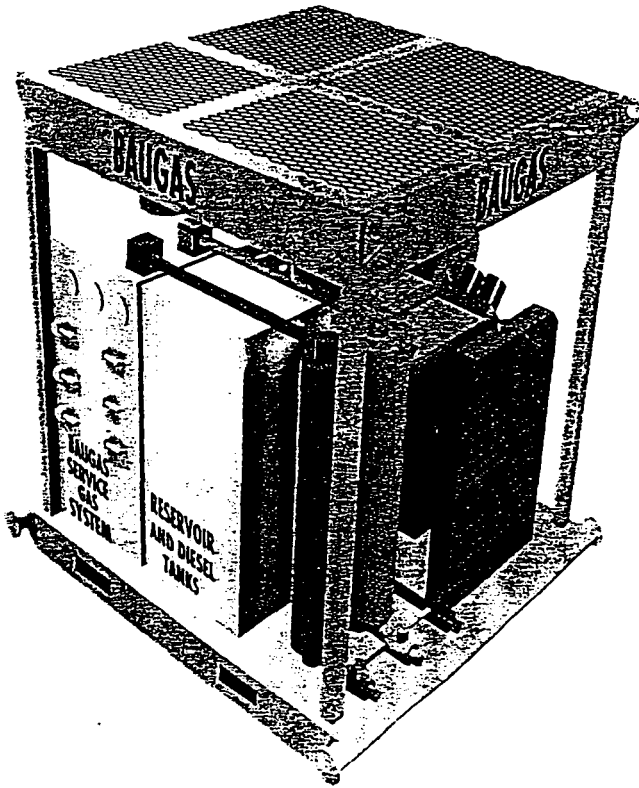


Fig. 8. Diesel exhaust nitrogen source unit (Baugas Co.).

4. ACKNOWLEDGEMENTS

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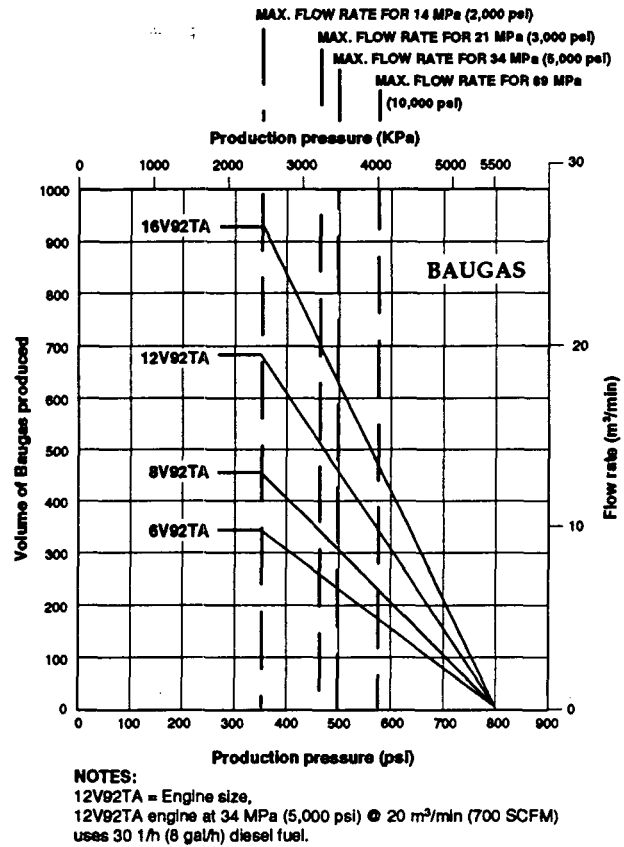


Fig. 9. Nitrogen source performance characteristics.

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