HOT WATER DRILLING IN ANTARCTIC FIRN, AND FREEZING RATES IN WATER-FILLED BOREHOLES

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Abstract

Hot water drilling systems are suitable for applications in which the objective is to gain rapid access to a glacier, ice sheet or ice shelf for seismic shooting, installing temperature sensors, access hole studies or retrieving stuck core drills. The Ross Ice Shelf Project (RISP) hot water drilling at J-9 showed that the decrease in water temperature at the nozzle was 1°C/30 m (1.8°F/100 ft) of depth. The boiler was rated at 2.5×10^6 watts. It produced 320 l/m of water heated from 2°C to 98°C (1.75×10^6 watts). The success of a smaller hot water system (150 kW) used by PICO in 1979-80 at Dome C, Antarctica, in ambient temperatures of -40°C illustrated the speed and reliability possible under extreme environmental conditions.

Browning Hot Water Drill

The Browning hot water drilling conducted in 1978 as part of the Ross Ice Shelf Project (RISP) at J-9 demonstrated that access holes could be drilled rapidly to depths of 420 m. The drill consists of a single 2.5 megawatt boiler, heat exchanger, downhole pump, booster pump and reels of hose with a 6-m long 5-cm diameter pipe and nozzle (Browning et al., 1979). By using water created and stored in an in situ water well it was not necessary to provide surface storage for water during drilling (Figures 1-3). This drill was used in 1978-79 to drill three access holes through 420 m of ice at the RISP camp J-9.

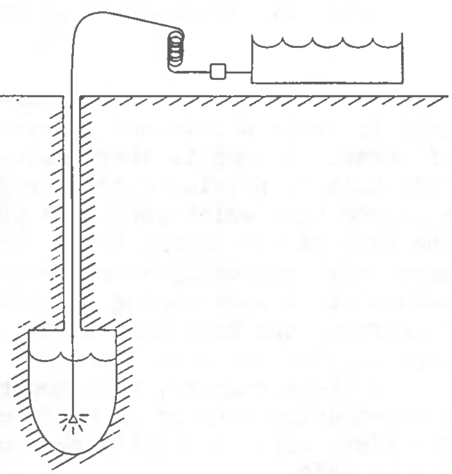

Figure 1. Development of water well using surface water

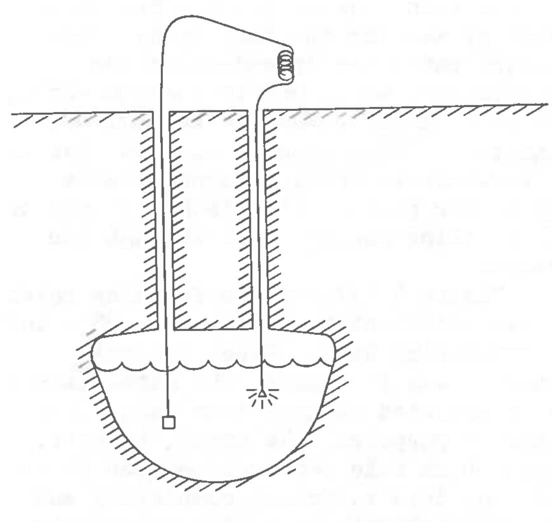

Figure 2. Drilling of second access hole

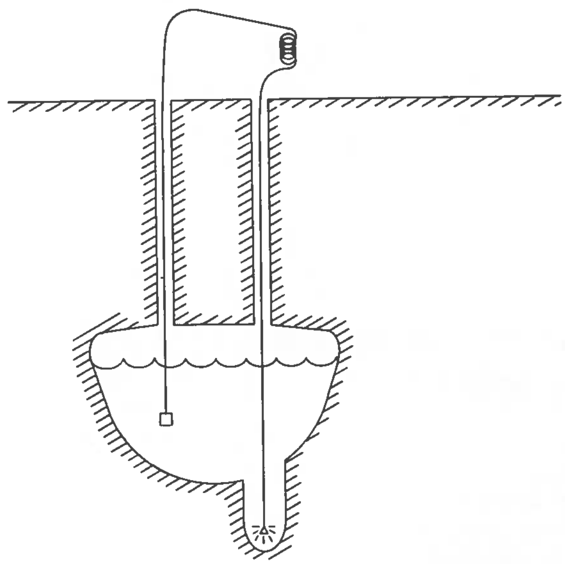

Figure 3. Drilling in progress

First, water from a storage tank is used to drill a hole and provide a bulb of water. A pump is then lowered into this bulb to provide water for drilling a second hole which continues through the bulb as the access hole. The water level will gradually decrease due to the volumetric change during melting. Therefore, the bulb must be of sufficient size to keep the pump immersed.

A 76-cm diameter hole was drilled at a penetration rate of .7 m/min using 320 l/min water initially heated from 2°C to 98°C.

During drilling, the rate of decrease in water temperature at the nozzle was recorded as 3.3°C/100 m depth. Freezing rates began at 10 cm/24 hours, decreasing to less than 5 cm/24 hours after three weeks of keeping the hole open. These closure rates are dependent on ice temperature, which in this case was -28°C, and to a lesser extent on initial hole diameter. These results suggest that it is possible to drill to considerable depths for placing thermistor strings or for drilling access holes through ice shelves.

Figure 4 illustrates freezing rates at two different temperatures (-28°C and -17°C) during RISP. Since the hole diameter was irregular, the rates cannot be interpreted as more than values for estimate purposes. We noted, however, that a 30 cm hole required between three and four days to freeze completely and that measurements made with ultrasonic detectors gave results within 5 mm of those measured with the caliper.

Calculations of freezing rates with a moving boundary are difficult and depend on many assumptions. Those made by Yen and Tien (1976) suggested complete freezing of a 30 cm hole in eight hours. The heat balance integral method of Lunardini (1981) gives results within 25 percent of these measured.

PICO Hot Water Drill

The success of a smaller hot water drill system designed by PICO and used at Dome C, Antarctica, showed that in ambient temperatures of -40°C hot water drills could be used reliably to drill shot holes and recover stuck ice core drills to depths of 70 m. The PICO hot water drill system is a noncoring shallow-depth drill consisting entirely of off-the-shelf components. The drill consists of three Malsbary oil-fired water heaters (two Model 21-H and one Model 221-H) used in varying combinations to melt the required snow in a 2250 l reservoir tank, and to heat the meltwater for drilling. The heated water in the tank was pumped through a Synflex hose and out through a nozzle to melt the hole. For use at high altitudes, the oil burner nozzles were changed, reducing the fuel consumption rates to 7 l/hr and 21 l/hr, respectively.

At Dome C during late December 1979 through early January 1980, the PICO hot water drill was used to provide shot holes of depths between 15 m and 60 m for the University of Wisconsin-Madison Geophysical and Polar Research Center's seismic program (Kuivinen et al., 1980). PICO drilled a total of 37 shot holes at 17 sites over a 30-km area, providing 1085 m of holes in ten days of drilling. Water pools in these holes at about half the firn-ice transition depth, so many of the holes at Dome C were unusable below 40-45 m. The Geophysical and Polar Research Center seismic investigations included a wide-angle reflection profile, a P-wave refraction profile, two large separation refraction shots and surface wave recording.

Upon completion of the drilling in support of the seismic program, PICO used the hot water drill to melt free the NSF-Swiss shallow drill stuck at 65 m depth during the previous season. The drill was recovered intact, and was retrograded to Lincoln for overhaul.

It was found that only 1135 l of water were needed to drill a 60 m hole.

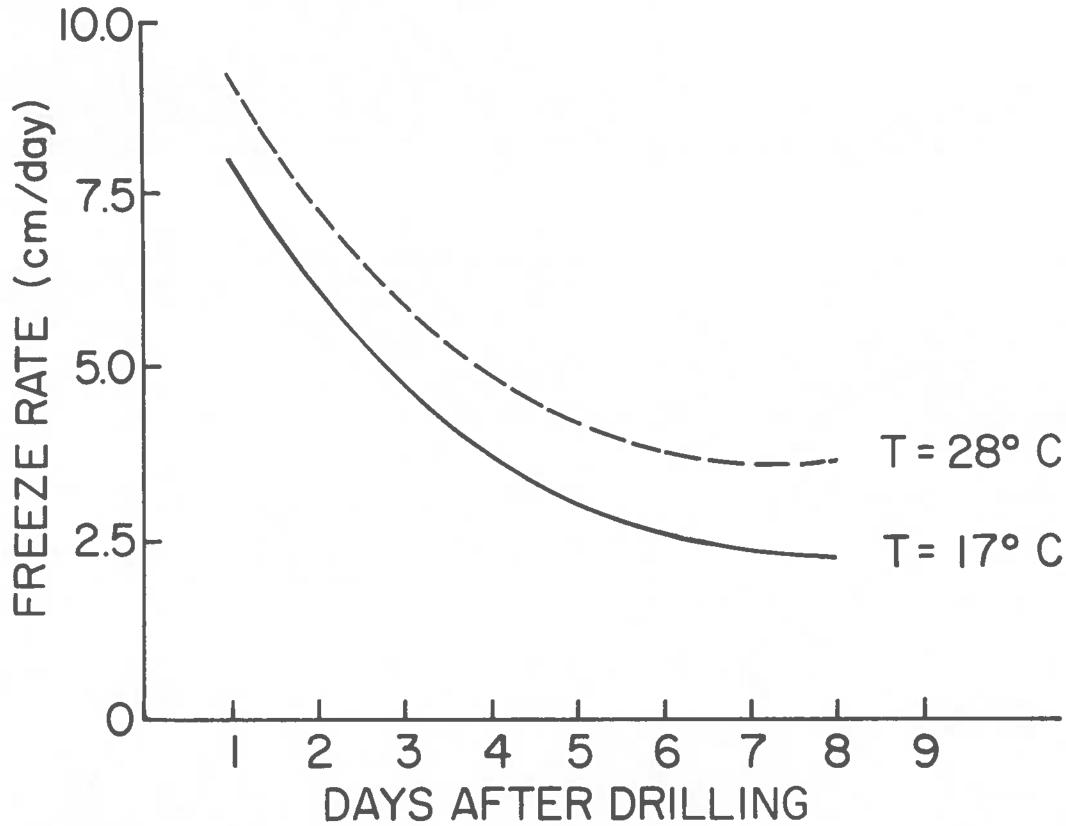

Figure 4. Freezing rate as a function of time for two different temperatures (depths) in the Ross Ice Shelf.

By raising the water in the tank to 5°C it was possible to deliver water to the drill head at 95°C (7°C above boiling) because of the back pressure at the nozzle. Water delivery was at the rate of 32 l/min with 160 kW used to heat the water during the drilling stage. Drilling rates ranged from 360 m per hour for the top 10 m of the firn to 120 m per hour to reach 60 m with a minimum hole diameter of 7.6 cm. Cycle time for each 60 m hole was about 2.5 hours, which allowed us to drill holes at two sites per day.

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