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INSTRUMENTS AND METHODS

A NEW VERSION OF A STEAM-OPERATED ICE DRILL

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Abstract. A further development of the Howorka steam-operated ice drill is given. It is mounted on a pack frame for easy transportation in rugged terrain. A propane flame is used to vaporize water in a single-pass fire-tube boiler. The steam is delivered to the ice through a double-walled flexible hose and a straight guide tube with an exchangeable nozzle at the end. One hole, 25 mm in diameter and 8 m deep, can be drilled in 15 min; four such holes can be drilled with one tank of water and 10 with one tank of propane. Holes deeper than 16 m are impractical as heat losses in the hose become too large. Sturdy construction has been used and the drill has been tested and found to work satisfactorily under both temperate and arctic conditions.

Résumé. *Une nouvelle version de la sonde à glace à vapeur.* On donne un nouveau perfectionnement de la sonde à vapeur pour glace de Howorka. Elle est montée dans un emballage à armature en vue d'un transport facile en terrain accidenté. Un feu au propane est utilisé pour vaporiser l'eau dans un tube à feu bouilleur en un seul passage. La vapeur est acheminée vers la glace par un tuyau flexible à double paroi et un tube guide rectiligne avec un nez échangeable à l'extrémité. Un trou de 25 mm de diamètre et de 8 m de profondeur peut être foré en 15 min; quatre trous semblables peuvent être forés avec un seul réservoir d'eau et dix avec un seul réservoir de propane. Des trous plus profonds que 16 m sont impraticables car les pertes de chaleur dans le tuyau deviennent trop grandes. La construction est robuste et la sonde a été entièrement contrôlée et trouvée apte à travailler de manière très satisfaisante aussi bien dans les conditions arctiques que tempérées.

Zusammenfassung. *Neue Version eines Dampfbohrers für Eis.* Eine Weiterentwicklung des Howorka-Dampfbohrers wird beschrieben. Sie ist auf einem Traggestell montiert, das ihren Transport in schwierigem Terrain erleichtert. Im Kessel wird mit einer Propanflamme durch ein Feuerrohr mit einfachem Durchang Wasser zum Verdampfen gebracht. Der Dampf wird durch einen doppelwandigen Schlauch und ein starres Führungsrohr, an dessen Ende eine auswechselbare Düse angebracht ist, ins Eis geleitet. Ein Loch von 25 mm Durchmesser und 8 m Tiefe kann in etwa 15 Minuten gebohrt werden. Eine Füllung des Dampfkessels reicht für vier, eine Propanflasche für 10 solche Löcher. Löcher tiefer als 16 m sind nicht praktikabel, da der Wärmeverlust im Schlauch zu gross wird. Der Bohrer besitzt eine sehr robuste Konstruktion; seine Erprobung erwies seine Brauchbarkeit sowohl unter gemässigten wie arktischen Bedingungen.

Introduction

In 1967 the Glacier Project Office of the Water Resources Division, U.S. Geological Survey, Tacoma, Washington, obtained a steam-operated ice drill from Norges Vassdrags- og Elektrisitetsvesen for the purpose of installing ablation stakes on the South Cascade Glacier, Washington. The drill was loaned to the author during parts of the summer of 1968 for placing movement stakes on the Nisqually Glacier, Mt Rainier National Park, Washington. The drill was based on the Austrian ice drill of Howorka (Howorka, 1965; unpublished), and differed from the Austrian one in that it used propane instead of butane and no provision was made for adding snow as well as water. In practice, it was found that the Norwegian drill was too fragile for use in rough terrain and was too bulky for easy back-packing. Nevertheless its superiority over hand drills was evident and so it was decided to build a stronger drill, permanently mounted on a pack frame and containing a tube boiler for greater efficiency, having a large opening for snow and a number of other minor improvements, some of which were suggested by Howorka (1965).

Design of the boiler

The basic working principle is the same as in Howorka's design, except that propane is used for the energy source. One kg of propane can supply 5.0×10^7 J of heat energy; assuming no heat losses, this is capable of raising the temperature of 18.4 kg of water from 0°C to the

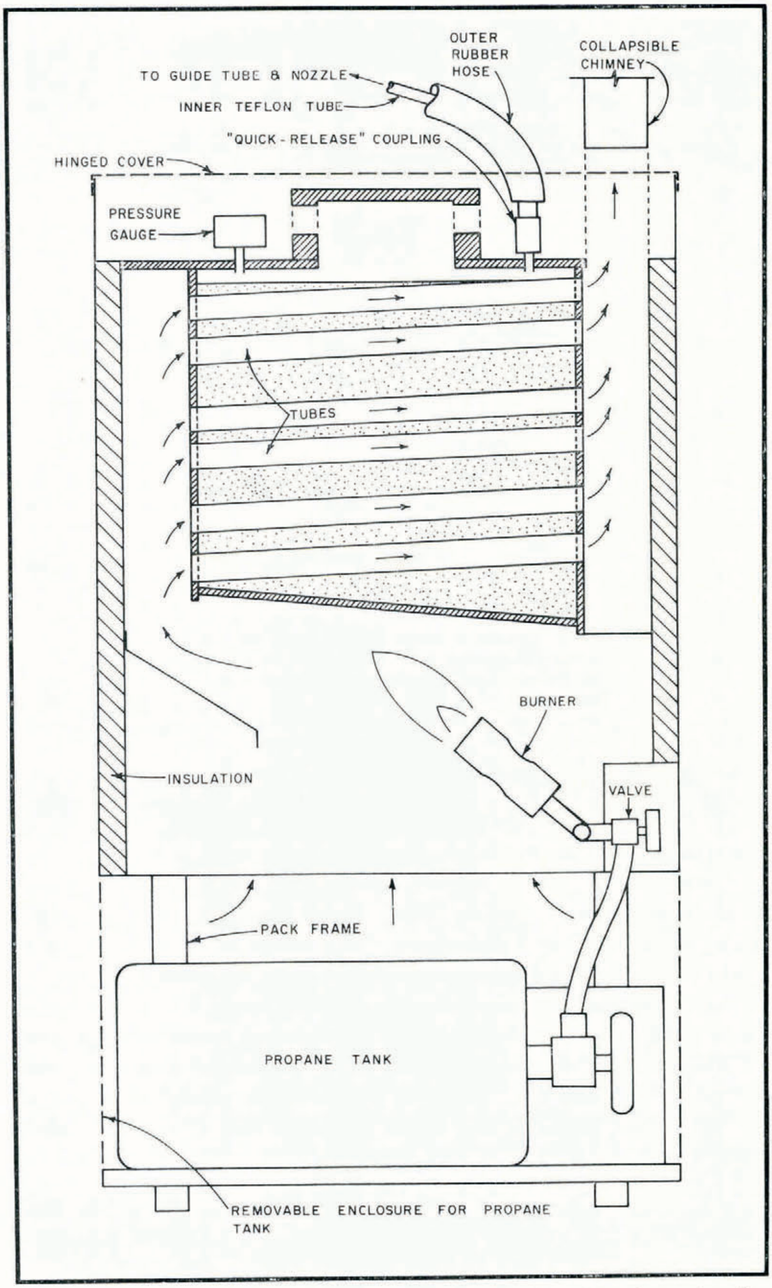

Fig. 1. Schematic diagram of steam-operated ice drill as seen from the front. The safety valves and small vent on the left side (visible in Figure 2) are not shown.

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boiling point, vaporizing it and then raising the steam's temperature to 141 °C (the temperature at the drill's working pressure). In turn, this steam is capable of melting 150.6 kg of ice (at 0°C). This is equivalent to a hole 25.4 mm in diameter and 324 m deep. Propane was chosen because it is more readily available and has a higher vapor pressure at low temperatures than butane.

The basic features of the drill are shown in Figures 1 and 2 (engineering drawings are available from the author on request). The material used is T-6 6061 aluminum alloy, except where stainless steel was used to withstand the high temperatures of the propane flame.

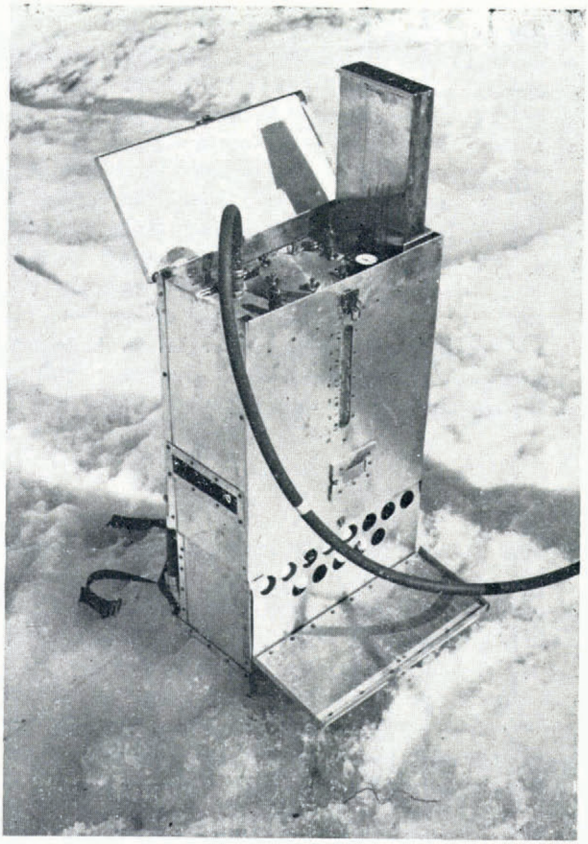

Fig. 2. The ice drill in use on the Blue Glacier. The adjustable vent on the left side is necessary for proper exhausting of the burner gases. The water-level tube on the front is protected by a plexiglass (polymethyl methacrylate) window; below this is an opening for lighting the burner. The complete propane tank enclosure is shown in use, although it is not necessary in temperate conditions.

The boiler is a single-pass horizontal fire-tube type, rectangular in shape with dimensions 267 mm long, 260 mm high, and 152 mm deep. It contains 24 tubes, each 19 mm in diameter, and will hold approximately 6.9 l of water, of which about 6 l can be used up safely. The 100 mm diameter opening at the top is covered with a lid held down by six bolts and wing nuts and sealed with a silicone O-ring. An extendable chimney helps improve the draft through the tubes. Gases can also pass over the front and back surfaces of the boiler to increase further the heat exchange. The top of the boiler is fitted with a quick-release coupling for the steam hose, a pressure gauge, and two safety valves, one of which is set to release at

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3.5×10^5 N m^{-2} overpressure (slightly above normal operating pressure) and the other to release at 5.2×10^{-5} N m^{-2} overpressure (the pressure to which the boiler was tested). The safety valves exit horizontally and do not endanger the operator when they open. All openings in the boiler are in the top so that the depth of the boiler can be kept to a minimum and so that the drill can be used upright; the top plate is reinforced to offset weaknesses caused by these openings.

The boiler is surrounded on all four sides by a double-walled wind screen with 25 mm of high-temperature insulation between the walls. A hinged top is provided for protection during transportation and a vertical glass tube on the front of the boiler provides a water-level indicator. The boiler is bolted to a contoured aluminum pack frame and a sturdy shelf is fastened to the bottom of the frame to allow the unit to stand upright on a level surface. Teeth are provided on the front edge of this shelf to grip the ice when the drill is used on a sloping surface. The shelf also provides support for a commercially-available steel propane tank. The propane burner is fixed inside the unit and is connected to a valve on the outside. A flexible hose connects the valve to the propane tank; this allows the tank to be easily removed and refilled. The propane tank can be enclosed if the drill is to be used at temperatures well below 0°C and it becomes necessary to increase the vapor pressure of the propane.

The overall dimensions of the unit (excluding pack frame) are 432 mm wide, 794 mm high, and 210 mm deep. The basic weight with propane tank enclosure and pack frame is 20.4 kg. The propane tank weighs an additional 4.5 kg and can hold 1.8 kg of propane. Completely full of propane and water the unit weighs 33.5 kg but it is seldom transported very far with a full boiler. Weight has not been sacrificed at the expense of strength and the result is a drill which will stand much abuse. Finally, the entire drill has been constructed so that any part can be easily replaced. Thus only the boiler proper is heli-arc welded; the rest is bolted together.

Design of the hose and drill tip

The Howorka design for the hose and drill tip was found nearly adequate and only minor changes were made. The steam hose is made in 8 m lengths with an outside diameter of 25.4 mm, and consists of an outer rubber hose and an inner teflon hose, with an air gap between. This double-walled hose is connected to a guide tube with the same outside diameter. The guide tube, 1.8 m long, consists of an outer fiberglass tube and an inner teflon tube. The bottom end of the guide tube is brass; the teflon tube passes through the brass and feeds the steam into a replaceable nozzle. The condensed steam and melt water travel up to the surface between the outer hose and the ice. Experiments with blocks of clear ice showed that the spray pattern of the nozzle was very important. The optimum drilling rate occurs when ice is melted uniformly over the entire cross-section of the hole. This requires some radial holes as well as a central forward hole. Four nozzles with different hole configurations were tested; the one which gives the fastest drilling rate has a 1.18 mm central hole and six 1.18 mm holes radiating at an angle of 30° from the central hole. The use of more radial holes than in the original design caused an increase in drill rate by about 10%.

Use of the drills

Two drills have been built at the University of Washington. One drill was used by the U.S. Geological Survey on the South Cascade Glacier during the summers of 1969 and 1970 and on Gulkana and Wolverine glaciers, Alaska, in March and April 1970. The other drill was used by the author on the Nisqually Glacier in 1969, on the sea ice at Barrow, Alaska, in March 1970 and on the Blue Glacier, Washington, in September 1970. When the drills were first used, inadequate exhausting of the burner gases caused the burner to go out, especially if any breeze was present. This has been alleviated with the addition of a small vent on one side of the boiler and both drills are now working satisfactorily. They have been used for installing ablation and movement stakes, thawing out stilling wells in gauging stations, heating tea, and installing supports for a glacier weather station. Although the drill is considerably heavier than the Norwegian version it is less tiring to carry around, largely because it is designed to fit flat against the back. Sufficient space is maintained between the boiler and the bearer's back so that the drill can be immediately carried without waiting for it to cool down. Pressure decreases slowly so that the drill can be in use within a minute or so of arriving at the next drilling site, provided water does not have to be added. Unintentional field tests have shown that there is no danger of scalding if one falls; furthermore, there is adequate peripheral shielding around the boiler to protect the operator should a break develop.

Field tests under temperate conditions

Tests were made with one of the drills on the Blue Glacier in September 1970. The time necessary to bring a full tank of water from 0°C to the boiling point and then to a normal working overpressure of 3.2×10^5 N m^{-2} is about 12 min. An additional 12 min are necessary if snow must be melted first. In Figure 3 the depth of a hole 25.4 mm in diameter is plotted against time for various lengths of hose. With one length of hose an 8 m hole can be drilled in ice in 14–15 min; this is a drill rate of 0.55 m min^{-1}, which is more than twice as fast as the Howorka drill rate (Howorka's drill is 21 mm in diameter; this one is 25.4 mm). In firn the drill rate increases to 0.90 m min^{-1}. About four 8 m holes can be drilled in ice with one tank of water. One tank of propane lasts approximately 180–190 min; this is sufficient to bring a full boiler to the boiling point three times and to drill about ten 8 m holes in ice. When

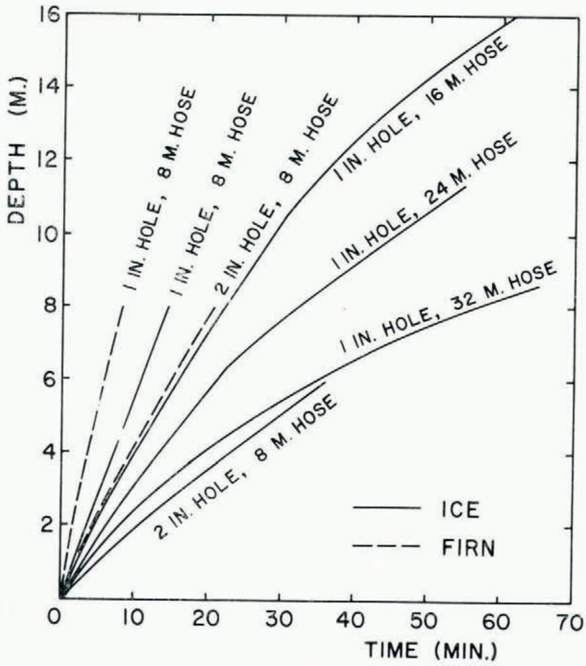

Fig. 3. Drilling curves in ice and firn for both 1 in (25.4 mm) and 2 in (50.8 mm) holes. The curve for the 1 in hole in ice is also shown for various lengths of hose.

compared with the theoretical limit of 324 m for 1 kg of propane this implies an overall efficiency of about 14%. About 70% of the available energy is lost between the propane and the steam; the portion of the remaining 30% which is lost by the hose is given in Table I for the various lengths of hose used. From this it is apparent that 16 m is the practical limit to the depth of a hole since the heat losses in the hose become too large when more than two sections of hose are used. In fact, two of the curves in Figure 3 show an abrupt decrease in drill rate in the lower half of the hole. This might be caused by steam starting to condense before it reaches the nozzle rather than outside the nozzle. Any improvements in drill rate or depth of hole will have to come either through increasing the operating steam pressure or through using a hose with better heat insulation properties. The heat losses through the hose completely dominate the performance of a steam drill, but the author seriously doubts if improvements can be made here.

Table I. Drilling rates and percentage of the thermal energy of the steam lost in various lengths of hose. These values are for the nozzle with the optimum spray pattern and for a steam overpressure of 2.8×10^5 N m^{-2} (40 lb in^{-2}). Use of more than two sections of hose is impractical as too much heat is lost

No. of sections of hose used	*Total length of hose* (m)	*Drilling rate* (m min^{-1})		*Heat lost by hose* (%)	
		at surface	*at 8 m*	*at surface*	*at 8 m*
1	8	0.55	0.55	50	50
2	16	0.47	0.32	57	71
3	24	0.34	0.16	69	85
4	32	0.27	0.11	76	90

A nozzle 50.8 mm in diameter was also tested. The drilling curves for this nozzle in both ice and firn are included in Figure 3. In ice the drill rate is about 0.15 m min^{-1}, or about 9 m h^{-1}. This is to be compared with 6 m h^{-1} for a 2 kW electric hot point drill of the same diameter.

The drill is thus extremely useful for drilling holes up to 16 m deep. Once set up the drilling is effortless and the drill tip cannot be damaged by hitting rocks in the ice. Like the Howorka drill, this one drills a hole true to size near the bottom, which then slowly widens to about 35–40 mm at the top of an 8 m hole. Work on the Nisqually Glacier has shown that the drill can be used even in ice containing many small rocks, pebbles or sand. The drill rate may decrease by as much as a factor of 10, but a hole can nevertheless be drilled; in fact, use of a steam drill enabled the author to place stakes in areas which would have been impossible with a hand drill. Furthermore, drilling through a snow-slush-ice sequence, normally a difficult procedure by hand, presents no problems with a steam drill.

Field tests under Arctic conditions

Tests were also performed on the sea ice at Barrow, Alaska, to see if the drill would work under Arctic conditions as well as temperate ones. Air temperature varied between −35°C and −40°C. The only problem encountered was when the hose was allowed to cool down to the ambient air temperature; when the hose was connected to the boiler the steam condensed and froze before reaching the drill tip. This plug of ice would not move and the drill could not be used. However, if steam was run through the hose indoors then the hose would take 20–25 min to cool down outside. Thus if the drill was used at least this often there were no problems. The drilling rate was about 0.50 m min^{-1} and approximately fifteen 2 m holes (25.4 mm in diameter) could be drilled through the sea ice with one tank of water. The propane tank was enclosed on the sides and bottom (except for air intake holes) but was open to the burner at the top. This kept the propane well vaporized and the burner worked as well as it does under temperate conditions. The hole drilled in the ice was very true to size over its entire length and the water would not start to refreeze until several minutes after the drill was removed.

The advantage of using a steam drill over a hand drill is certainly questionable for a few short holes, but it would definitely be superior for drilling deeper holes or a great number of holes. The purpose of these tests was simply to see if the drill would work under very cold conditions and apart from the preheating limitation imposed by the hose no problems were encountered. Moreover, this limitation could probably be circumvented by installing a valve in the steam hose so that while holes were not being drilled steam could be allowed to flow slowly through the hose at a rate just sufficient to prevent freezing.

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