A DANISH CONTRIBUTION TO THE FAMILY OF HOT-WATER GLACIER DRILLS

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ABSTRACT

A high-pressure hot-water drill has been used successfully down to 400 m in ice with a temperature of -2°C at the margin of the Greenland ice sheet. An average speed of about 5 m per minute for the top 100 m has been achieved. The complete drilling system, inclusive of tools and 600 m of drilling hose, has been reduced to 473 kg with the heaviest single unit weighing 127 kg. The drill system is equipped with a guiding system consisting of a load cell and a built-in inclinometer.

INTRODUCTION

During 1986 glacier-hydrological investigations for a possible hydro-electric power station near Jakobshavn, West Greenland had reached a stage where improved knowledge of subglacial topography and drainage were a decisive factor (Thomsen et al., 1986). As one way to attack this array of problems it was decided to build a hot-water drill which seemed to be the fastest and most reliable system for reaching the bottom of the ice.

The surface topography of the ice sheet is too rough to use sledges so all but the shortest (10-50 m) movement of equipment must be done by helicopter, setting rather strict limits on the weight and bulk of the largest/heaviest items to be moved. As the most common small helicopter operating in Greenland is the Bell 206 Jetranger the maximum weight carried in one haul has to be limited to less than 250 kg. A further restriction is that transport between airport and the ice at the start and end of the season is by a S61N helicopter which is not equipped with a hoist, meaning that all equipment has to be loaded and unloaded by hand. Weight criteria for the design of the heaviest single unit was therefore set at 125 kg making it possible to lift it 1.5 m from the ice up to the cargo door of the helicopter.

EQUIPMENT

The basic requirements for hot-water drilling, moderate amounts of high-temperature water at high pressure, are the same as for industrial high-pressure cleaners. In principle it is possible to buy a commercially available high-pressure cleaner, connect it to the drilling hoses and start drilling right away.

However, commercial systems tend to be very heavy and compact making them almost impossible to handle and very hard to service under field conditions. It was, therefore, decided to use individual components from the commercial systems and modify them to meet our specific needs.

One of the design criteria was that no single unit should weigh more than 125 kg which led to the construction of separate power and heating units. During operations they are bolted together acting as a single unit (see fig. 1) which can be moved by helicopter in a single haul.

Power and pump unit

This unit consists of a 6 kW four-stroke gasoline engine with a 1:2 reduction gear connected to a high-pressure piston pump through a flexible coupling (see fig. 2). At 1750 r.p.m. the pump delivers 18 l/min. of water with a pressure of up to 100 bar at which pressure the relief valve is set. The engine is also connected through a belt drive to a small 0.6 kW 220 v generator which is used for the ignition system in the heater. Fuel consumption is 2.5 l of gasoline per hour. The whole unit is mounted on a stainless steel frame and the total weight is 79 kg.

Heating unit

The heating unit is a water coil with an oil burner (modified for using jet-A1 fuel). Airblower and oil pump are driven by a flexible axle which is connected to the rear end of the generator axle (see fig. 2). Current for the ignition is drawn from the generator.

The water coil is used in a vertical position making it easy to empty when drilling is completed. The air for the burner is blown in from the bottom of the heater, passing between an inner and outer mantle up to the burner which is at the top. This construction ensures preheating of the air and a low outer surface temperature together with a very high heating efficiency. With fuel consumption of 11.6 l/h corresponding to 113 kW and an outlet temperature of 82°C the heating efficiency under field conditions is better than 90 %.

The heating unit is safeguarded by a safety valve, water-flow contact, thermostat, and high-temperature cutoff and is equipped with gauges for temperature and pressure. It is mounted on a stainless steel frame and the weight is 127 kg, slightly more than the design goal of 125 kg.

Drilling hose

This is a 1/2" heat resistant high pressure hose with working limits at 121°C and 138 bar in lengths of 100 m fitted with hydraulic system couplings and weighs 21 kg/100 m. The drill stem is 2 m long with a 25 mm outer diameter and an inner tube of 10 mm with the space between filled with lead in the bottom half. Both tubes are made from stainless steel. The end of the drill stem is fitted with a tapering bronze tip of 180 mm as suggested by Iken et al (1977) and Taylor (1984) with interchangeable stainless steel nozzles of 25 mm. Further equipment is a lightweight tripod with winch and pully (see fig. 3) plus a low-pressure centrifugal pump used when drilling water has to be drawn from farther away.

The total weight of the complete drilling system (with 600 m of high pressure hose) inclusive of tools and spare parts is 473 kg. Table 1 gives a more detailed listing of weights for different parts of the whole system.

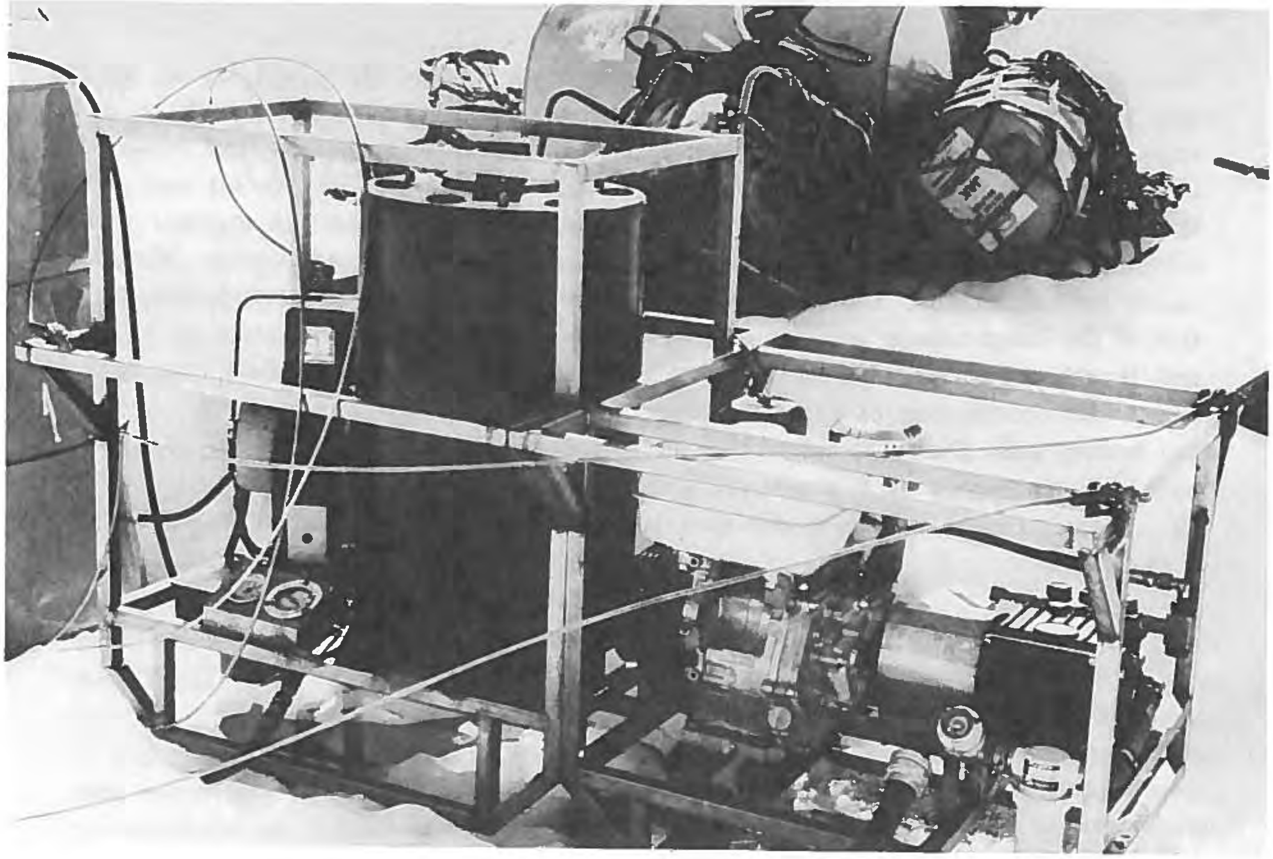

Fig. 1 - Central part of the drilling system. To the right, a gasoline engine and high pressure pump form the power unit. The heating unit is to the left. Units are bolted together for field operation.

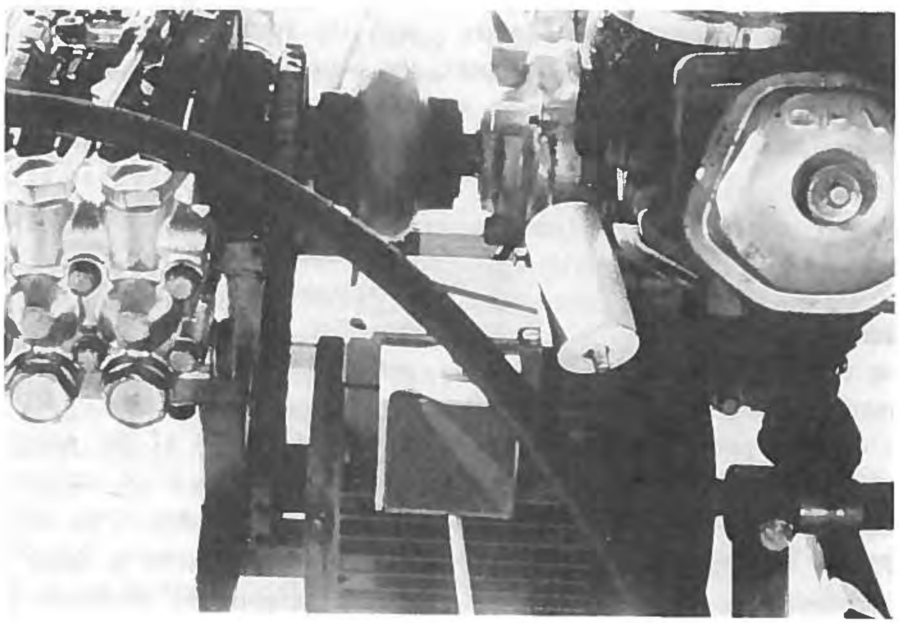

Fig. 2 - Details of power unit hook-up. The hose running diagonally in the figure is the high-pressure water from pump to heater. Note flexible axle from rear end of generator. Safety shield has been removed for clarity.

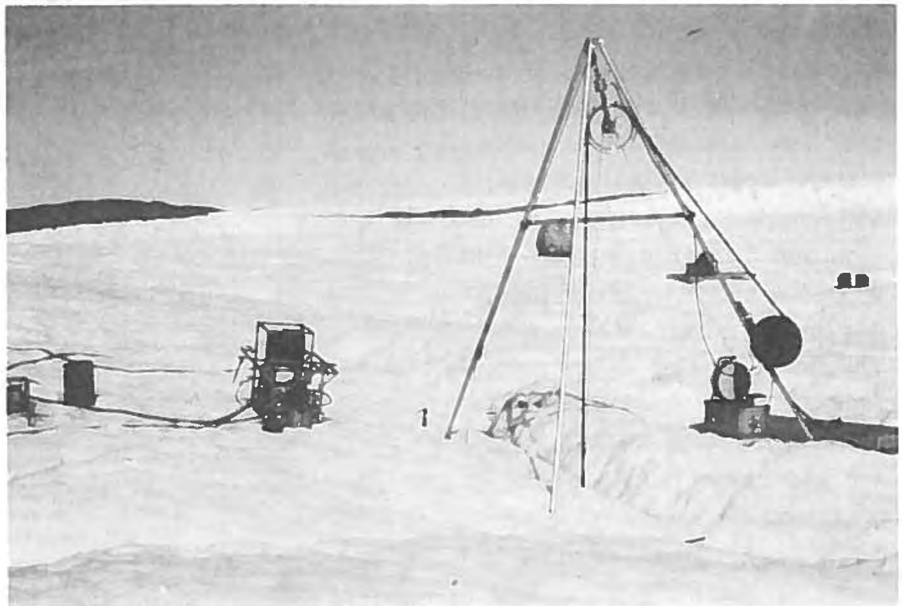

Fig. 3 - Light weight tripod with winch and pulley. The reel for the inclinometer cable is located below the winch.

Table 1 - Breakdown of weights

Power and pump unit	79	kg
Heating unit	127	"
Tripod, winch and pulley	73	"
Drilling hose (600 m)	126	"
Water pump	19	"
Tools and spare parts	16	"
Cables	20	"
Drill stem	6	"
Load cell & inclinometer	7	"

Total	473	kg

CONTROL EQUIPMENT

Inclinometer

In order to monitor tilting of the drill stem a new inclinometer was constructed. The design goal was to avoid hinges or bearings and to make it small enough to fit inside a 32 mm tube on top of the drill stem together with the 10 mm inner tube leading the hot water from the hose to the nozzle. Range should be from 0° to about 10°.

The finally adapted design is based upon the principle of a capacitor. It consists of an acrylic tube with an outer diameter of 28 mm and 1 mm walls closed with lids which fit tightly around the inner 10 mm tube. To make the whole system airtight 0-rings are bolted to the lids with acrylic covers (see fig. 4 and 5). To the inside of the upper lid a copper washer with an outer diameter of 26 mm and an inner diameter of 11 mm and a thickness of 1/10 mm is glued and sealed with a plastic spray. A lead is soldered to the washer and goes through both lid and cover.

The acrylic tube is filled with mercury, through screw holes in the bottom lid, until about 2 mm of space is left. The left-over space is filled with silicone oil no. 200 with a viscosity of 200 cts.

Due to lack of time the necessary electronic system is rather crude and hence too sensitive to temperature changes. Basically it stabilizes an incoming DC voltage, converts it to a 500 kHz AC voltage which is applied to copper washer and mercury as the variable part of a two-capacitor voltage divider. The signal is then rectified, amplified and led to the surface via a three-lead cable running along the hose. The same cable is used to supply the DC voltage from a battery at the drill rig. The outgoing voltage is read off a meter at the winch. The electronic components are wrapped around the inner tube and cast in epoxy which is covered by the metal tube seen in fig. 5

In principle it should be possible to determine directions of tilt (when coupled with a compass) by dividing the washer in segments read off separately. With an area of only 4.36 cm^2 it is, however, possible that the signals will be drowned by noise in the system.

Load cell

To measure the tension of the hose as in the USGS system (Taylor 1984) a load cell is placed between the top of the tripod and the pulley. It is a commercial unit, temperature compensated with a load capacity of 500 kg and an overall accuracy of 0.1 % (factory figures). The load cell is run by the same battery as the inclinometer and is read off a second meter at the winch.

FIELD EXPERIENCE

During the two field seasons 1987 and 1988 a total of 5657 m has been drilled with the deepest hole being 390 m. In 1987 a nozzle with an inner diameter of 2.7 mm was used for all holes and this gave a pump pressure of 35 bar with one length of 100 m hose. The 1988 drillings were done with a 2.5 mm nozzle which required a pump pressure of 50 bar.

As the first drilling already showed that the equipment fulfilled expectations of a drilling speed of 2-3 m/min. only a few holes were actually timed with the results shown in Table 2. During drilling the hoses are stretched out on the ice and are successively connected as drilling progresses and the measurements refer to the time used until the next 100 m length of hose has to be connected. No corrections have been attempted to compensate for "difficult" drilling conditions as when the drill penetrates layers of ice with debris. On the

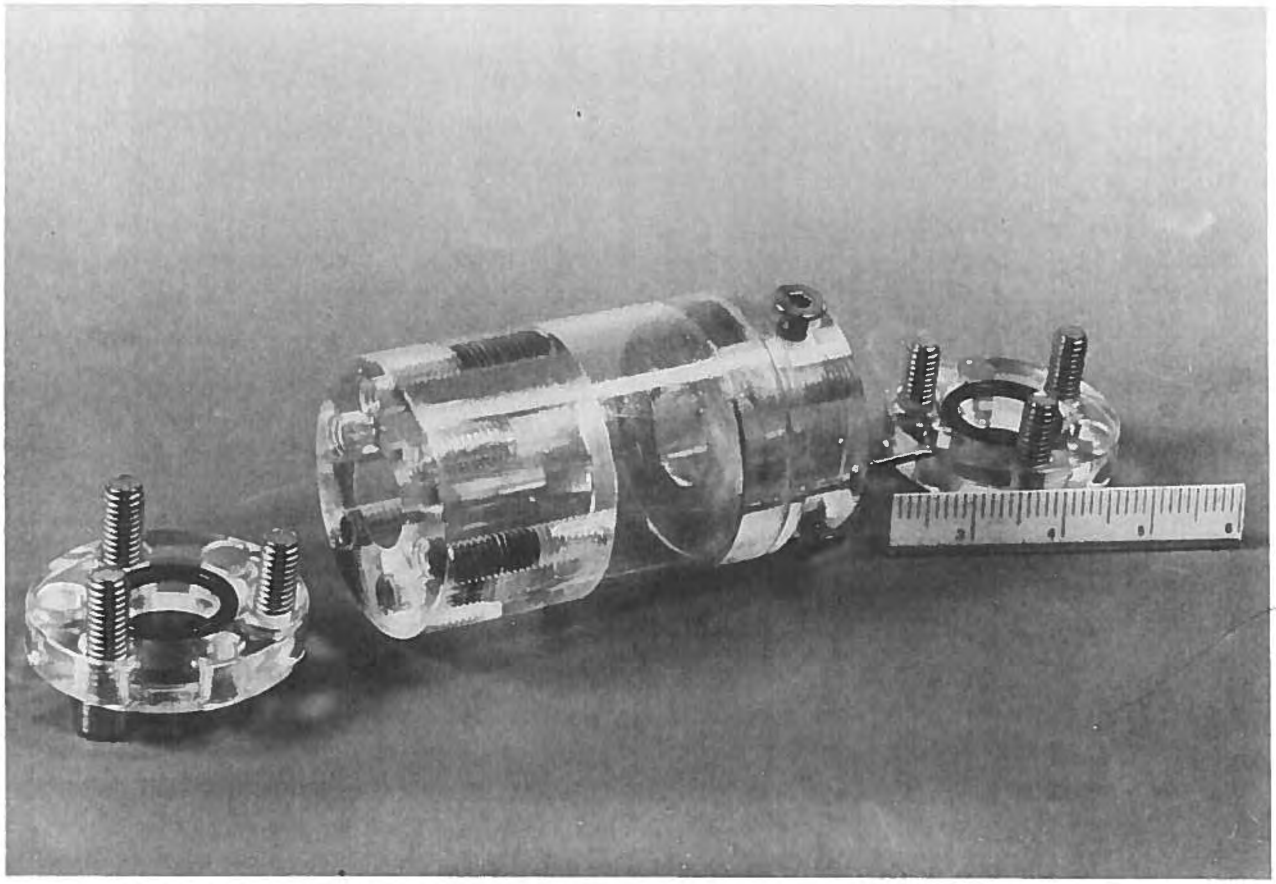

Fig. 4 - Acrylic part of the inclinometer with the top part facing right. For details see text.

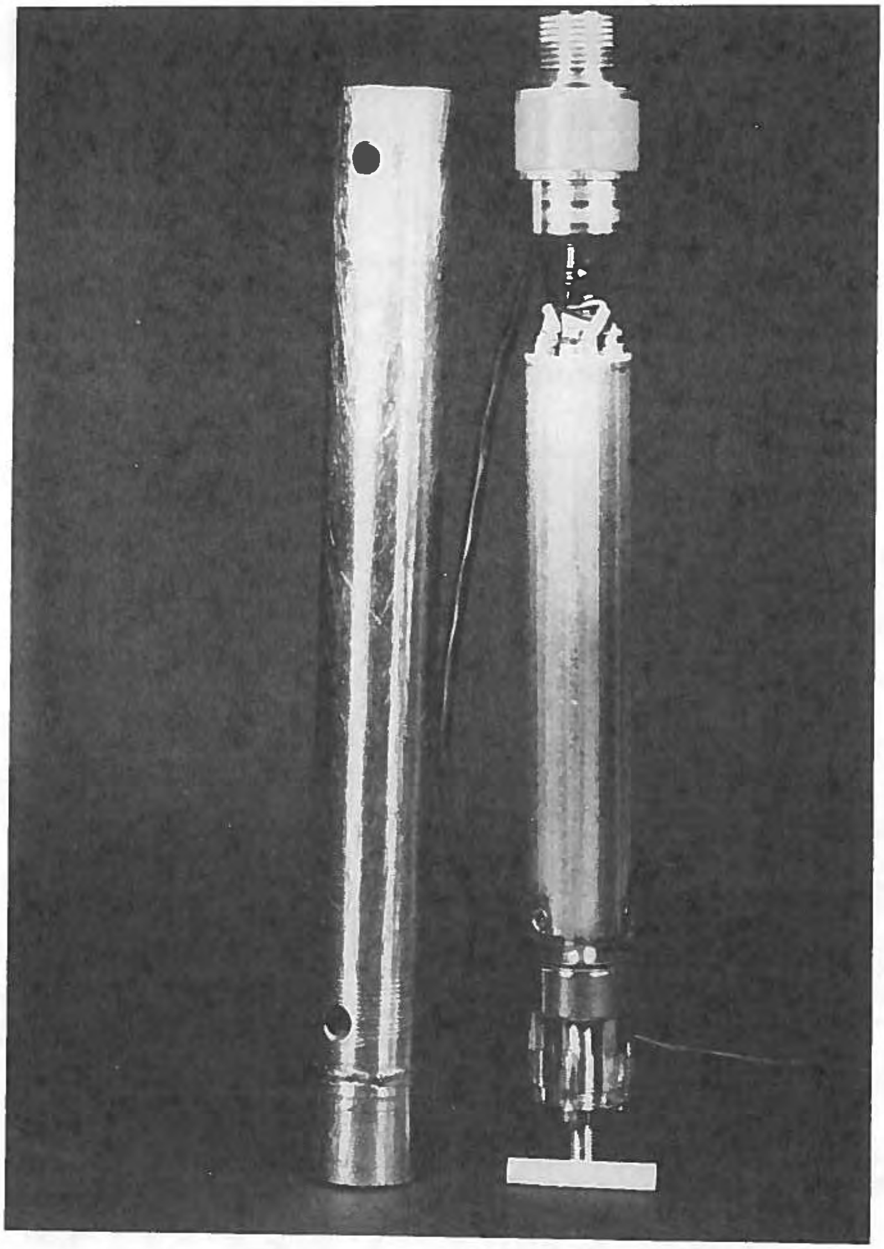

Fig. 5 - Inclinometer with protective cover taken off. The bottom part is the "variable capacitor" with the electronic system covered by the metal tube. Total length of system is 31 cm. Scale at the bottom is 4 cm.

Table 2 - Drilling speed and depth for hot-water jet Påkitsup akuliarusersua, Jakobshavn, West Greenland August 1987. Units are metre/minute.

	Depth Intervals				Max Depth
	0 - 90 m	90 - 190 m	190 - 290 m	> 290 m	m
	4.1	2.6	2.2	-	298
	6.0	-	-	-	305
	5.6	-	-	-	270
	6.4	3.6	2.1	1.1	382
	4.5	4.0	-	–	298
Mean drilling speed	5.2	3.3	2.1	1.1	

other hand it should be noted that none of the holes listed in Table 2 encountered the more extreme conditions when drilling through a 5-10 m layer, very often between 150 and 250 m depth, required 1-2 hours.

The load cell and inclinometer (which were both added in the 1988 field season) worked very well together, immediately alerting the operator to any slowing of progress or deviation from the vertical. They were most useful when debris layers were encountered as the operator could add pressure on the drill tip by paying out more hose, as long as the drill stem remained vertical. This procedure often resulted in a more rapid penetration than when the drill tip had little or no contact with the ice. When a constant pressure had been maintained for at least half an hour and no progress resulted it was assumed that the bottom had been reached.

COMMENTS

Both power and heating unit have worked most satisfactorily as during the two field seasons drillings were never stopped due to any malfunctioning in either unit. However, they were both destroyed under a helicopter operation at the end of the 1988 season and they will be rebuilt after the same concept.

As for the load cell the present millivolt signal should be converted to a weight read-out as this would be very helpful, e.g. when packing helicopter loads.

The electronics of the inclinometer must be changed as it is presently much too sensitive to temperature changes. During operation in 1988 it had to be reset every time a new hose was added. This was done by halting drilling until the temperature at the inclinometer had reached a new equilibrium and using the subsequent reading as a zero point. Together with a temperature compensation the output from the inclinometer should be changed from the present voltage to a frequency signal. Also the silicone oil used in the present system should be exchanged with one of lower viscosity as the hydraulic damping effect is a little too high.

Major commercially available units used in the drilling system.*

Burner and heater

K.E.W. Industri. Heater type 03V rated at 103 kW, with thermostat, high-temperature cutoff, safety valva, water-flow contact, temperature and pressure gauges.

Pump

Interpump. Model W912 with ceramic pistons, rated at 18 l per min. at 1750 r.p.m. and maximum pressure 100 bar with safety valve set at the same pressure.

Engine

Honda. Type GX 240 gasoline engine with 1:2 reduction gear rated at 6 kW (8 HP) at 3600 r.p.m. Engine and pump are connected via a flexible coupling on the gear shaft.

Generator

Grundfos International. Type MG 7132-14 rated at 220v, 2.6A, 50 Hz at 2810 r.p.m. Generator is connected to the engine with a belt drive counterbalancing the difference between the gear shafts 1750 r.p.m. and the 2810 required.

Centrifugal pump

Honda. Type WB 10 rated at 150 l/min. with max. 38 m of water level difference.

High pressure hoses

Imperial Eastman thermoplastic hose type HK 408 SAE 107 R A 3465, 12.7 mm (1/2") inner diameter, rated working pressure 138 bar, temperature range -46°C - 121°C constant. Weight in air is 21 kg/100m.

* Use of brand names is for identification purposes only and does not constitute endorsement by the Geological Survey of Greenland.

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