EVALUATION OF HOT WATER DRILLS

by

K.-H. Bässler and H. Miller
Alfred-Wegener-Institute for Polar and Marine Research.
Bremerhaven, FRG.

1 - ABSTRACT

Caused by the increasing geophysical and glaciological field investigations in polar regions more and more drill holes in cold firn and ice are required. Using hot water drilling a fast drill hole production is possible. Existing evaluations for hot water drills were derived from drill tests in temperate ice for small hole diameters (Iken et al, 1977 ; Taylor, 1984). The present paper shows a possibility, based on thermal calculations in ground engineering to evaluate the necessary heat and the drill rate dependent on

- the hole diameter,
- the firn (ice) density,
- the in-situ temperature of the firn (ice),
- the water flux,
- the water temperature.

For quick estimates some graphs for fixed hole diameters are given.

2 - INTRODUCTION

For some time past the use of hot water drills for the hole production in firn and ice exhibits an increasing trend. For field investigations without the necessity of ice cores this technique offers crucial advantages compared with electromechanical drills :

- a multiplication of the drill speed,
- penetration of ice shelves and ice layers mixed with sediments,
- little susceptibility to mechanical defects,
- the possibility for the recovery of stuck drills.

In the framework of the German Antarctic research Engelhardt et al, 1987 tested a hot water drill on the Ekstroem - and Filchner/Ronne Ice Shelf, which was developed from the University of Münster in co-operation with H. Rufli. In spite of bad weather conditions and technical problems with the winch they were successful in the penetration of both ice shelves in depths of 208 m and 460 m. Reaming of the holes from 5 cm to 10 cm for the installation of a thermistorchain was not possible. Because of the difficulties in reaming holes, caused by the deviation of the nozzle in the pre-drilled hole, the direct production of holes with greater diameters should be considered.

Therefore a model based on thermal calculations in ground freezing was derived which allows the evaluation of the heat and the resulting drill rates dependent on the density, the ice temperature, the water flux and - temperature for various hole diameters. Handy graphs enable quick estimates.

3 - BASIC EQUATIONS

Iken et al, 1977 and Taylor, 1984 defined relations for the determination of drill rates based on drill tests in temperate glaciers and on laboratory tests. In consideration of the flow conditions in the hose, which are decisive influenced by the shape of the nozzle and the efficiency of the hose insulation, they calculated the cooling of the water between input and output, the necessary latent heat and the drill rate. Both neglect the heat, which warms up the unmelted region around the hole.

The aim of the following analysis is the evaluation of the dissipated heat subjected to the firn density, firn temperature and the planed hole diameter. Assuming a linear relation between the dissipated heat and the waterflux at the nozzle warmed up to the temperature T1, the drill rate can be evaluated.

The equations, based on a modell of Sanger et al, 1979 describe the frost propagation around a freeze pipe in hydrous soils. Brine with a temperature of -20°C to -40°C flow through a double walled tube, installed in a hole. After the cooling of the soil further heat extraction leads to the freezing of the pore water and to the building of a frozen solid body. For the assignment of the heat extraction in the case of freeze pipes to the heat supply and the melting of ice the equations of Sanger et al, 1979 were taken over.

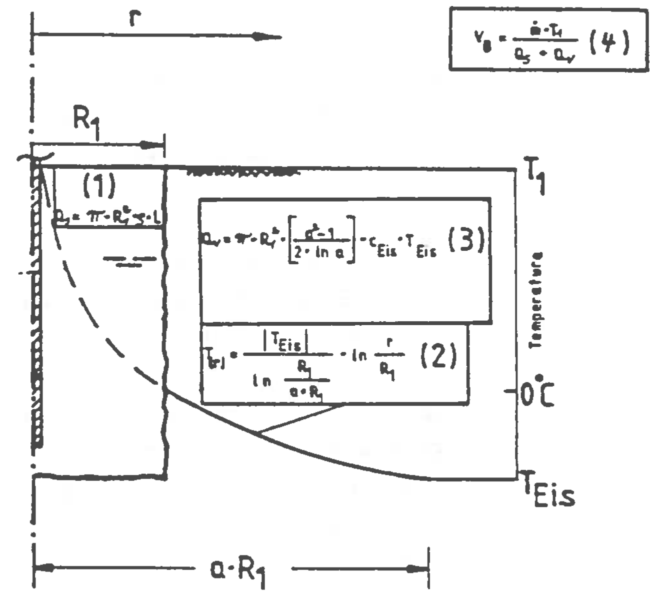


Fig. 1 - Simplified temperature regime around a nozzle during drilling.

In our model the freeze pipe is substituted for the hose. The ice corresponds to the frozen ground. Just as in frozen ground there is a change of the temperature field in the ice around the hole, which needs extra heat beside the latent heat. The cooling of the water in the hole and the occuring convection between water output and top of the hole are not under consideration. The following kinds of heat are considered.

- In connection with the hole diameter and the density of the firn the latent heat of melting Qs can be calculated according to equation (1) in fig. 1.

- Because of the melting of the hole there is a change of the temperature field in the ice between 0°C on the wall and the initial ice temperature in a finite distance from the wall.

Sanger et al, 1979 determined the threefold radius around the hole as the influenced region. Using equation (2) in fig. 1 for the description of the temperature-field the heat Qv needed for the warm up is evaluated according to equation (3) in fig. 1. With the total heat (Qs + Qv) related to the waterflux m with the temperature T1 the drill rate can be calculated using equation (4) in fig. 1.

4 - COMPARISON BETWEEN MEASURED AND CALCULATED DRILL RATES

Taylor, 1984 conducted drill tests in temperated ice and plotted the measured drill rates as a function of waterflux and temperature. There is a good agreement between the measured and with equation (4) calculated values (see fig. 2).

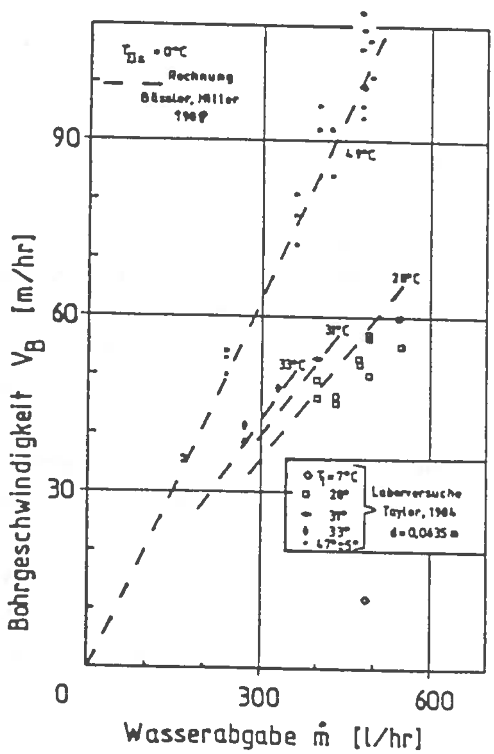


Fig. 2 - Comparison between measured and calculated drill rates.

It should be noted that Taylor's relations for the determination of the drill rates coincide with the doted lines, the plot of equation (4) in fig. 2 because of the fact that the ice temperature during the tests remained at 0°C and only the part describing the latent heat is needed.

To compare equation (4) including the heat Qv and the density relation a reported hot water drilling on the Ross Ice Shelf will be used.

Koci, 1984 describes the use of the Browning Hot Water Drill at J9 where a hole with a diameter of 76 cm was drilled with an average drill rate of 42 m/hr down to 420 m in depth. The waterflux was 19 200 l/hr with a temperature of 98°C on the surface. An average temperature decrease of 3.3°C/100 m was recorded. A linear evaluation of the down hole temperature T1 resulted in

$$T1 = 98 - (4.2*3.3)/2 = 91°C.$$

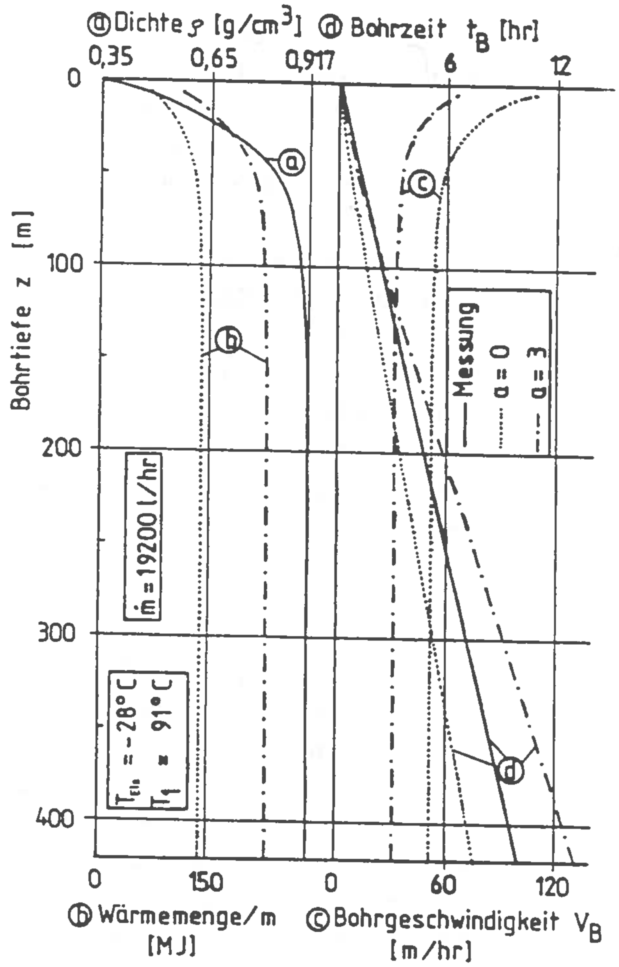


Fig. 3 - Calculated heat, drill rate and drill duration for a hole on the Ross Ice Shelf.

The in-situ ice temperature amounted to -28°C. Related to a depht-density profile for the Ross Ice Shelf near Little America V (Bender et al, 1960) the heat, drill rate and - duration for separated layers were calculated and plotted as a function of depth (fig. 3). The calculations were made for two cases. In the first case only the latent heat was considered (doted lines) and therefore smaller values were calculated compared with the reported average drill duration.

Using a value of a = 3 to describe the zone of temperature influence and an average ice temperature of -28°C the duration is higher maybe because of the neglect of the increasing temperature in the lower part of the ice shelf.

5 - DIAGRAMS FOR CALCULATION OF HEAT AND DRILL RATES

In fig. 4a - 4c diagrams for three hole diameters (0.1 m, 0.3 m, 0.6 m) are shown to evaluate the necessary heat according to firn density and temperature. With a waterflux of 1000 l/hr it is possible to estimate the drill rate using the lower part of the diagrams dependent on three different watertemperatures.

REFERENCES

Bässler K.-H., 1980. Untersuchungen zum optimalen Einsatz von Berechnungsmethoden zur thermischen Auslegung kältetechnischer Anlagen einer Gefrierbaustelle und zur Vorgehensweise. Diplomarbeit am Lehrstuhl für Grundbau und Bodenmechanik Ruhr-Universität Bochum.

Bender J.A., Gow A.J., 1960. Deep Drilling in Antarctica. Helsinki Symposium, International Union of Geodesy and Geophysics, Association of Scientific Hydrology.

Engelhardt H., Determann J., 1987. Tätigkeitsbericht zur Antarktisexpedition 1985/86. Berichte zur Polarforschung, Heft 33, AWI, Bremerhaven.

Helms W., 1980. Kritische Auseinandersetzung mit dem derzeitigen Erkenntnisstand über die Theorie der Bildung des Frostkörpers in horizontaler und vertikaler Erstreckung beim Abteufen von Gefrierschächten. Institut für Bergbaukunde und Bergwirtschaftslehre, TU Clausthal.

Iken A., Röthlisberger H., Hutter K., 1977. Deep drilling with a Hot Water Jet. Zeitschrift für Gletscherkunde und Glazialgeologie, Bd XII Heft 2, S. 143-156.

Koci B., 1984. Hot Water Drilling in Antarctic Firn and Freezing Rates in Water - Filled Boreholes. Ice Drilling Technology, CRREL. Special Report 84-34, p. 101-103.

Sanger F.J., Sayles F.H., 1979. Thermal and Rheological Computations for Artificially Frozen Ground Construction. International Symposium on Ground Freezing, Volume 2, P. 95-117, Bochum.

Taylor P.L., 1984. A Hot Water Drill for Temperate Ice. Ice Drilling Technology, CRREL. Special Report 84-34, p. 105-107.

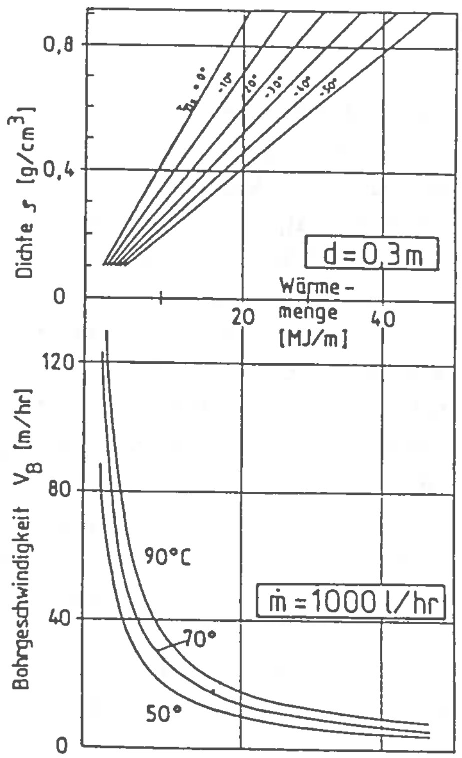
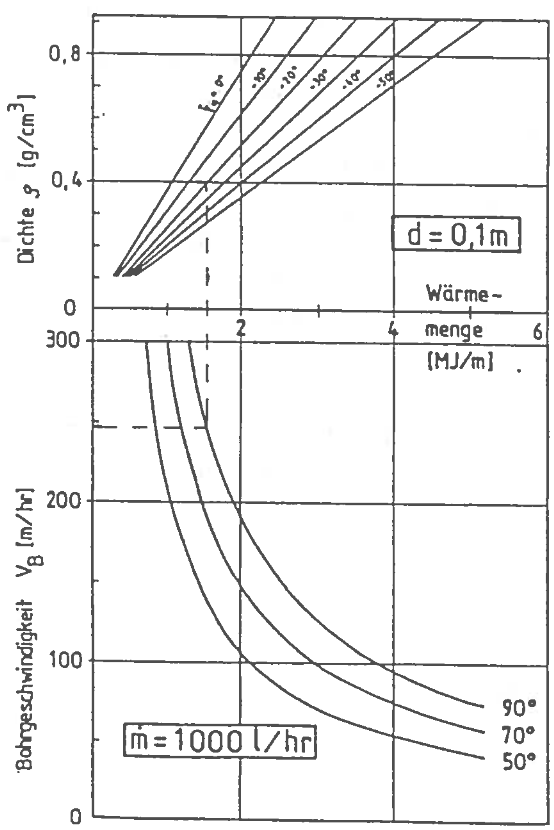
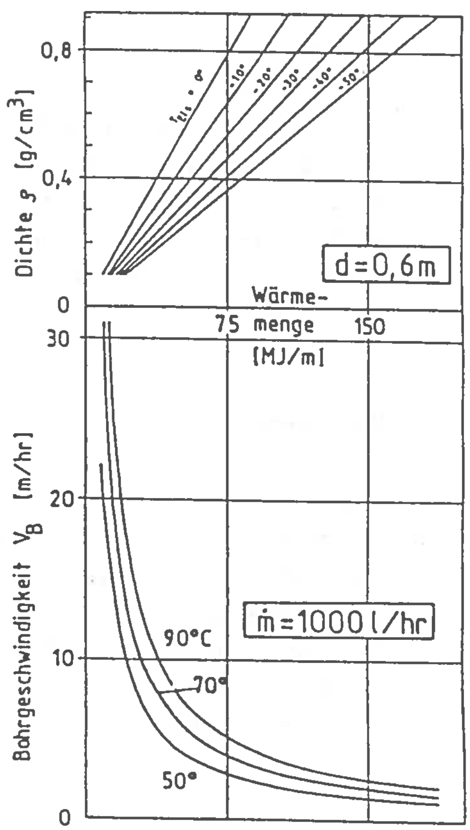
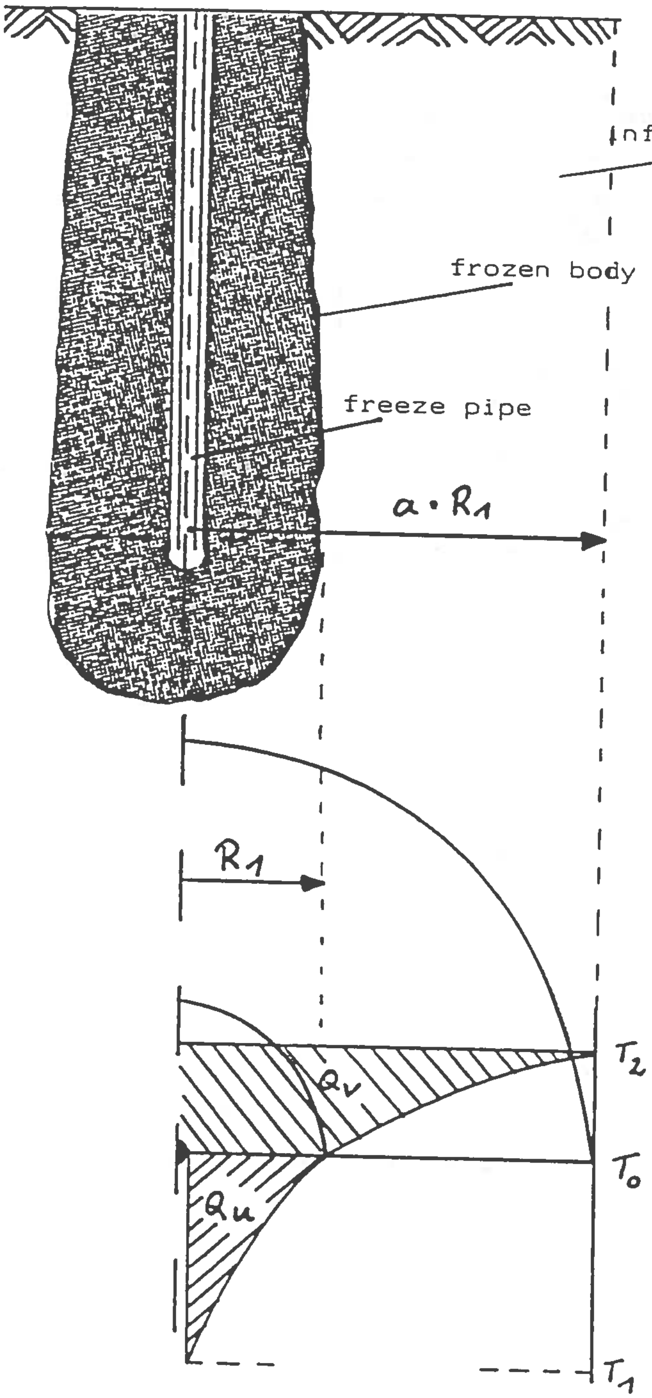


Fig. 4a-c - Diagrams for the estimation of heat and drill rate.



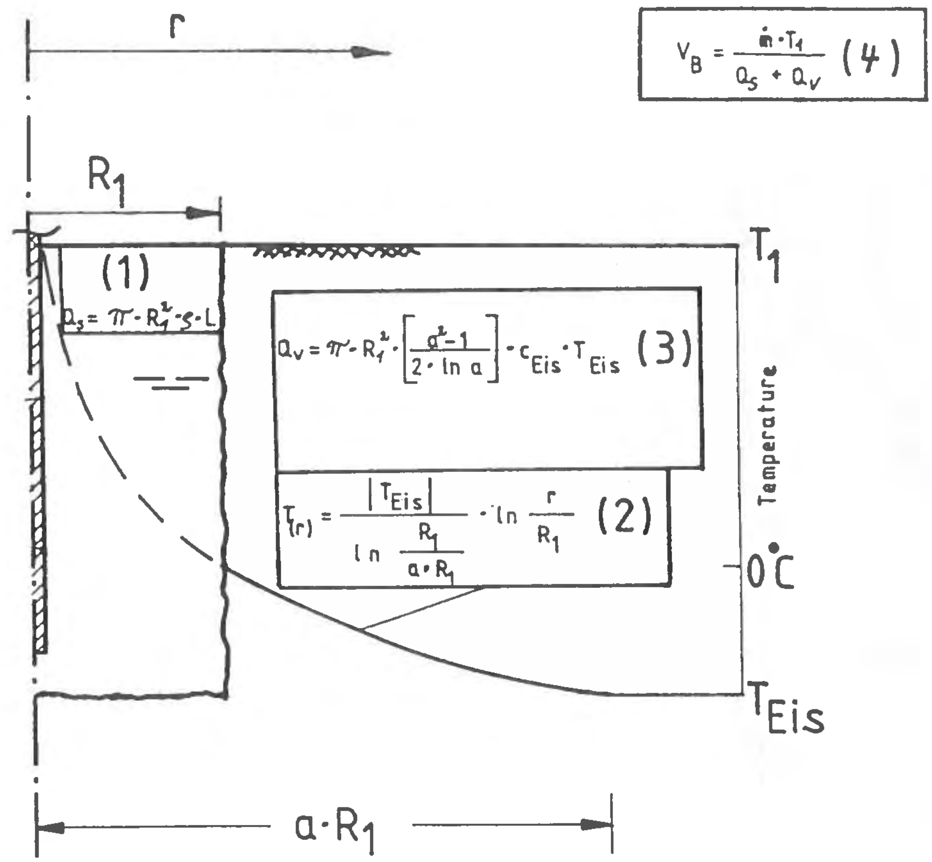


Engineering model used in ground freezing



R_1	radius of frozen zone
a	ratio between frozen and influenced region
T_0	freezing temperature of the ground
T_1	pipe wall temperature
T_2	initial temperature of the ground
Q_s	latent heat of melting
Q_v	heat needed to cool down the influencend region before freezing
Q_u	heat needed to cool down the frozen region

Transfer to hot water drilling



R_1	radius of melted hole
a	ratio between melted and influenced region
T_1	water temperature
T_{Eis}	initial ice temperature
Q_S	latent heat of melting
Q_V	heat needed to warm up the influencend region before melting
Q_u	heat needed to warm up the water in the hole after melting (neglected)
$\dot{m}$	water flow rate
V_B	drill rate
	firn density
C_{Eis}	heat capacity of ice