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HOLE LIQUIDS AND GASKETS FOR THE ISTUK DEEP ICE CORE DRILL

Niels S. GUNDESTRUP, Henrik B. CLAUSEN, Steffen B. HANSEN and Sigfus J. JOHNSEN

University of Copenhagen, Haraldsgade 6, DK-2200 Copenhagen N, Denmark

Abstract: Deep boreholes in polar ice sheets have to be filled with a liquid in order to prevent hole closure due to the overburden pressure of the ice. In Greenland, at ice temperatures of –32°C, the limit for open hole drilling is 400 m. In Antarctica, a depth of 900 m has been obtained in an open hole. All drilling to deeper depths needs to be performed in a liquid. The borehole liquid should have a density close to that of ice, be non-toxic, available in quantities at reasonable cost, compatible with the materials in the drill, non-aggressive to ice, and have a low viscosity to allow rapid drill movement in the borehole. In practice, no liquid has been available that can fulfill all the requirements. In the past, ethanol/water mixture, DFA/Glycol, DFA/TCE, JET-A1/PCE, DFA/F113, n-butyl acetate, and D60/F113 have been used. All liquids have their own advantages and disadvantages, and the use of all have involved severe compromises. In this paper, these ideal specifications are compared to those of the actually used hole liquids.

1. Introduction

In order to avoid borehole closure in a deep hole drilled in an ice sheet, the drill hole must be filled with a liquid of nearly the same density as that of ice (920 kg/m^3). For the GRIP drilling at the summit of the Greenland ice sheet, we found that the liquid should ideally satisfy the following criteria:

1) Have a density that can be adjusted between 920 and 950 kg/m^3 at temperatures between –10 and –32°C.
2) Have a freezing point well below the temperature of the ice (–32°C).
3) Have a viscosity less than 5 cSt at –32°C in order to expedite drill movements.
4) Be non-aggressive to drill and cable components.
5) Be non-aggressive to the ice hole wall in order to preserve hole diameter.
6) Be non-toxic in order to safeguard drill operators.
7) Be environmentally acceptable.
8) Be inexpensive and available in bulk quantities.

To our knowledge, not all of these requirements can be satisfied today, and some severe compromises have to be made in the selection of a suitable drilling fluid.

2. History

The two first deep ice core drillings, Camp Century 1966 (UEDA and GARFIELD, 1968a) and Byrd Station 1968 (UEDA and GARFIELD, 1968b), used a hole liquid mixed from Diesel Fuel Arctic Grade (DFA) and Trichloroethylene to increase the density. The drill used an ethyleneglycol/water mixture to dissolve the cuttings. This solution was then sucked into the drill and brought to the surface. Ethyleneglycol was thus not used as the hole liquid. The Byrd Station drilling ran low of trichlor eventually, and therefore extra glycol was added to the hole liquid in order to obtain the correct pressure at the bottom. This addition of glycol resulted in loss of the lower part of the hole the following year. Otherwise, the hole liquid worked well, and both the Byrd Station and Camp Century holes are still accessible today, 27 years after the drilling. The main problem with the liquid was the trichloroethylene, which is a very aggressive solvent.

For the Dye-3 drilling, a modification of this hole liquid was used: trichloroethylene was replaced by perchlorethylene. It was believed that because perchlorethylene has a 4 times lower vapour pressure than trichlorethylene, the change to perchlorethylene would expose the drillers to less risk. This was only partly justified because, as it turned out, the main risk for the operators was not the vapours, but the fine spray. This spray originated from the cable when the drill was raised out of the hole, and from the drill during cleaning and handling.

The Russians have used two different fluids. At Vostok, a hole liquid mixture made from DFA and F12 as densifier has been used (KUDRYASHOV *et al.*, 1984). Ethanol has been used in other drillings to 900 m depths (BOGORODSKY and MOREV, 1984; MOREV *et al.*, 1989). The French also have used DFA and F113. The Australians, for the Law Dome drilling, used DFA with perchlorethylene as a densifier.

When we had to decide on the hole liquid for the Summit drilling, we considered these alternatives, but were not convinced that any of these liquids was the best for our application. And worse, once selected, the hole liquid cannot be changed because elastomers selected for use in the drill are restricted to working in a few specific liquids. This is illustrated in Fig. 1, which shows results of tests in which two different elastomers are exposed to n-butylacetate and D80 (a kerosene type). To our knowledge, the only gasket material which can operate both in n-butylacetate and kerosene is teflon. However, teflon gaskets may not be as tight and as reliable as elastomers.

For the ISTUK drill, we used the following types of seals:

a) Teflon V-type, steel-backed thin walled (Fig. 2). This type is used in the piston sections and as the second ring in the motor section. It can operate in the lowest temperatures found in ice sheets, and can stand all hole fluids we know of. At the Dye-3 drilling, a predecessor for this type was used for the high-pressure seal around the motor exit shaft. The sealing properties were good enough, but the gasket wore down several shafts! So, in order to use this type of gasket with the motor shaft, an elaborate testing program was needed to confirm that a suitable combination of gasket and shaft could be found. Time did not allow this test.

b) Shaped carbon-filled teflon ring backed by an elastomeric O-ring (Fig. 3). This gasket was used as the main high-pressure gasket, both as a static gasket (Fig. 3b) and as the primary gasket around the rotating motor shaft (Fig. 3a). It worked very well, and except for minor leakages at intermediate pressures, no leakage was observed. From a hole liquid point of view, the carbon-filled teflon ring is compatible with all liquids in question.

The limitations are caused by the elastomeric backup O-ring. If this O-ring is demolished by the liquid, there will not be enough pressure at the teflon/wall contact line, and the gasket will leak. One possibility is to use a teflon-coated silicone O-ring as the backup ring. This may work for the static seals (although the low elasticity of the teflon-covered silicone ring gives problems), but not for the rotating motor shaft. The friction between the teflon-coated silicone O-ring and the rear side of the carbon-filled teflon ring

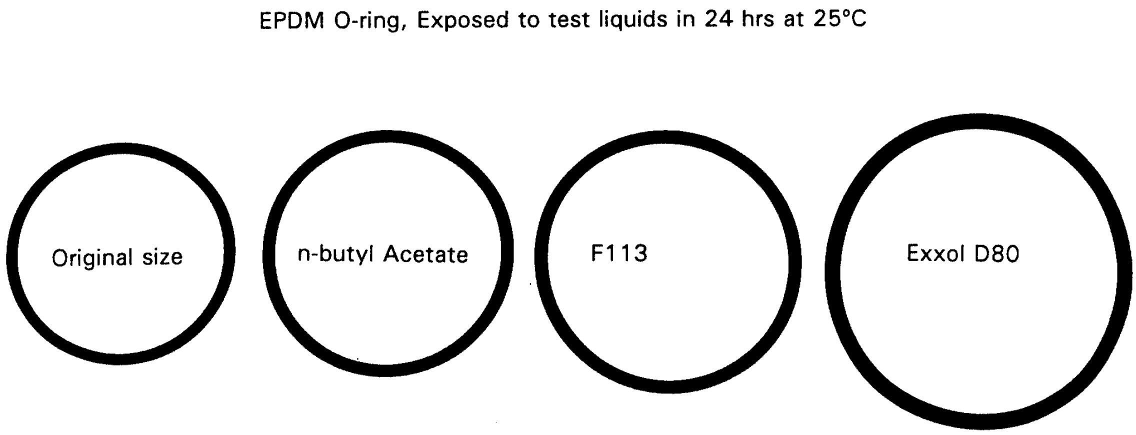

Fig. 1a. EPDM O-rings exposed to D80 (kerosene), F113 and n-butylacetate.

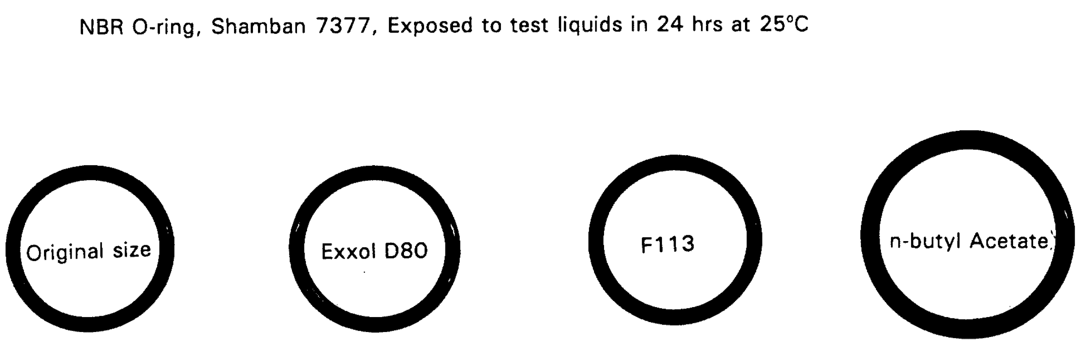

Fig. 1b. NBR O-rings exposed to the same substances.

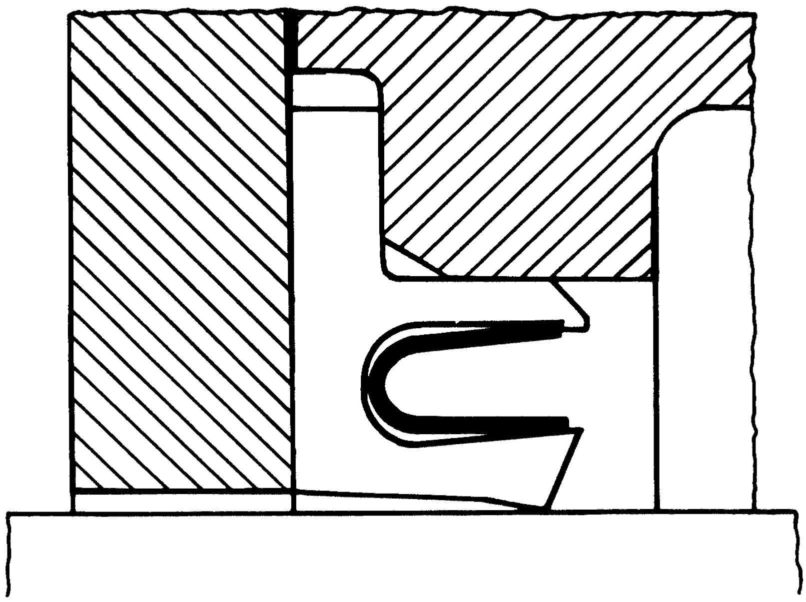

Fig. 2. Steel-backed teflon Variseal rotary gasket. Nominal pressure in the standard version is up to 400 bars.

may be less than the friction between the shaft and the teflon ring. Thus, there could be rotation between the two rings, which will be worn very fast.

In conclusion, we have not been able to locate a proven general purpose low-temperature, high-pressure gasket. The gasket type and material have to be chosen after the hole liquid is known.

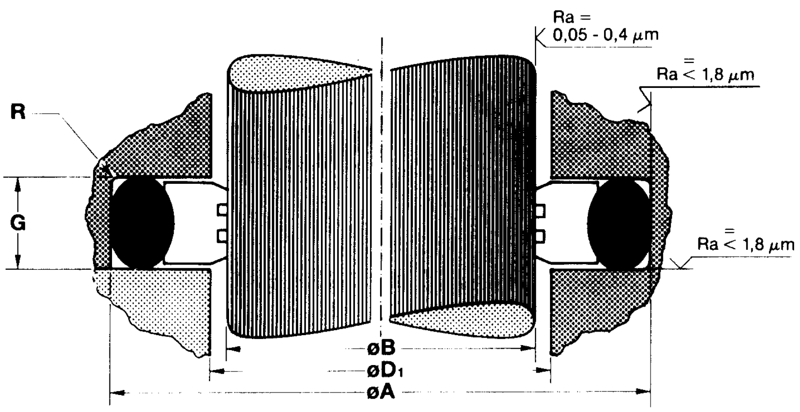

Fig. 3a. Shamban Roto Glyd Ring used as primary sealing ring on the motor exit shaft. With a clearance of 0.1 mm in radius, the rated pressure is 300 bars. An elastomeric ring presses the teflon ring against the shaft. The rear of the teflon ring is shaped to fit the O-ring.

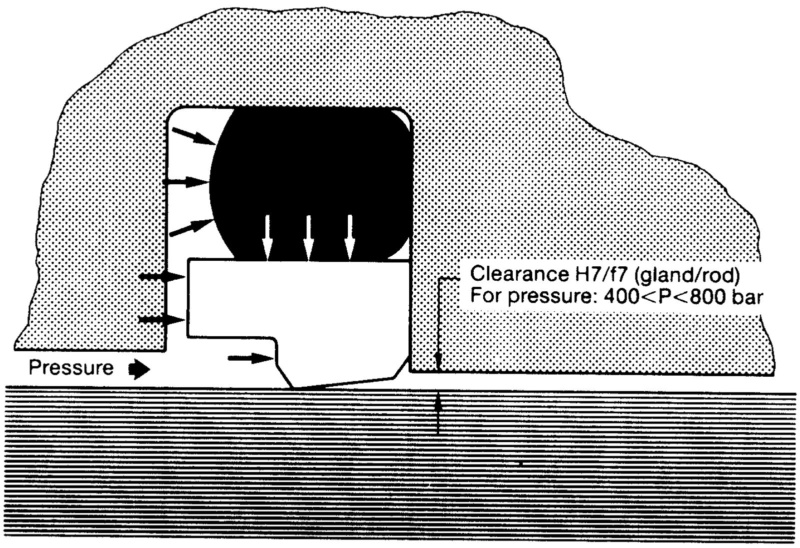

Fig. 3b. Shamban Stepseal K-R used for the stationary high-pressure gaskets in the high-pressure section. With a diameter of 100 mm, the rated pressure is 300 bars with 0.2 mm radial clearance

3. Selecting a Liquid

The following hole liquids were considered:

1) Ethanol/water mixture.
2) DFA/bromoil mixture.

3) n-butylacetate with anisole as a densifier for temperatures above –20°C.
4) D60/perchlorethylene.
5) D60/F113.

Of these alternatives, the ethanol/water mixture could not be used. The viscosity would be approximately 80 cSt, and the density 965 kg/m³. Any viscosity higher than 5 cSt slows down the drilling, and the high density reduces the lifetime of the hole significantly. The bromoil is considered a health risk, and it is expected to contribute to destruction of the ozone layer. Also, preliminary experience by PICO (Koci, private communications) indicate that the bromoil is difficult to handle. We are reluctant to use perchlorethylene, because it is considered to be a major health risk. This left us with two alternatives to consider: n-butylacetate and D60/F113.

The n-butylacetate met the selection criteria, except for two items: (1) Because it is a very aggressive solvent, it imposes a health risk for the operators (and remembering the Dye-3 experience, we respected the exposure to solvent sprays), and (2) because n-butylacetate is such an aggressive solvent, only a few elastomers are able to operate in this liquid. Based on the manufacturer's specification, only the compounds IIR (butyl rubber) and EPDM (ethylene propylene rubber) are not damaged by the liquid. IIR cannot be used at the low temperatures that exist in polar ice sheets. This leaves EPDM as the only elastomer possible, to our knowledge. However, because EPDM swells when exposed to hydrocarbons, it will not be possible to change the hole liquid once the drilling has started. The only gasket material that can sustain both n- butylacetate and D60 (hydrocarbon) is teflon.

The other choice is D60/F113. D60 is a hydrocarbon, intended for cleaning purposes, and not used previously for ice drilling. Its main specifications are:

Density: 790 kg/m³ at 15°C
Density of vapour: 5 times higher than air.
Boiling point: 190–221°C
Vapour pressure: 2 kPa at 38°C
Viscosity: 1.28 mPas at 25°C
Evaporation figure: 0.05 (n-butylacetate = 1)
Flash point: 62°C
Aromatic content: 0.1, max 0.5 wt%

From a driller's point of view, D60 can be considered to be Jet-A1, with low aromatic content and a narrow boiling range. This means that drops of D60 will evaporate completely in a relatively short time, and the low aromatic content means that the liquid is nearly without odour. D60 is fully miscible with F113, which is a well proven densifier, non-toxic for the drillers, but considered harmful for the ozone layer.

The Greenland Ice Core Project Steering Committee (SC) had to select between the two alternatives: n-butylacetate, which imposes a health risk for the operators and possible problems with the gaskets, or D60/F113 which presents no technical problems, but is considered to contribute to destruction of the ozone layer. After due consideration, the GRIP SC decided on the D60/F113 solution. It was also decided to recycle the liquid as efficiently as possible, and to store the wet ice chips in sealed drums. Thus, the release of F113 to the atmosphere could be kept to a minimum.

4. Experience

The D60/F113 hole liquid worked well. There was hardly any smell of the drilling fluid in the drill trench when the ventilation fans were operating. Compared to the Dye-3 drilling fluid, the D60/F113 liquid is much cleaner and leaves no residue on clothing exposed to the liquid. The degreasing of exposed skin was moderate, and caused no problems. The fluid evaporated quickly from the ice core. The fluid density was easy to adjust. The liquid was recycled in the same way as at Dye-3, separating hole liquid and ice cuttings in a filter. The empty D60 drums were used for the deposition of ice cuttings. There were no problems with the drill's gaskets being affected by the liquid. No contamination on the ice core from the liquid has been detected, and because of the clean liquid, only a minimal part of the ice has to be removed in the sampling process.

5. Future Drillings

The viscosity of D60 may be too high for ice temperatures lower than −40°C. Exxon produces two lower viscosity variants of this fluid family, named D40 and D30. The viscosity of these fluids is so low that they can be used for drilling in ice with temperatures down to −60°C (Fig. 4). Whereas D60 is called a kerosene type, similar to Jet-A1, D30 is more like turpentine. All three fluids are low in aromatics, almost without odour, and have the general toxicity characteristics of kerosene/turpentine.

The densifier constitutes a bigger problem. F113 will be not legal for use after 1995 because of its destructive effect on the ozone layer. Because the D60/F113 worked so well, alternative densifiers have been investigated. One possibility is HCFC-225. The main specifications for this fluid are:

Boiling point: 55°C
Density: 1550 kg/m^3
Freezing point: −97 to −94°C
Flash point: None
Influence on elastomers: Much like F113

The manufacturer's preliminary data for the Ozone Depletion Potential for HCFC-225 compared to F113 is:

	Life time (year)	ODP
WMO/AFEAS	2.2–2.7	0.025
NASA/NIST	1.5–1.7	
Phy. Chem. Lab.	1.5	0.01
Asahi Glass	2	0.01
F113	90	0.85

Thus, based on the present data, the ozone depletion should be 2 orders of magnitude less than for F113. If future investigations confirm this, it can be expected that HCFC- 225 will be acceptable for use for a long time. Toxicological studies also indicate that the toxicity is low, and that no chromosomal damage or gene mutation has been observed. Again, the data are preliminary. Although the fluid is available, it is not yet available in bulk quantities, and the price has yet to be established.

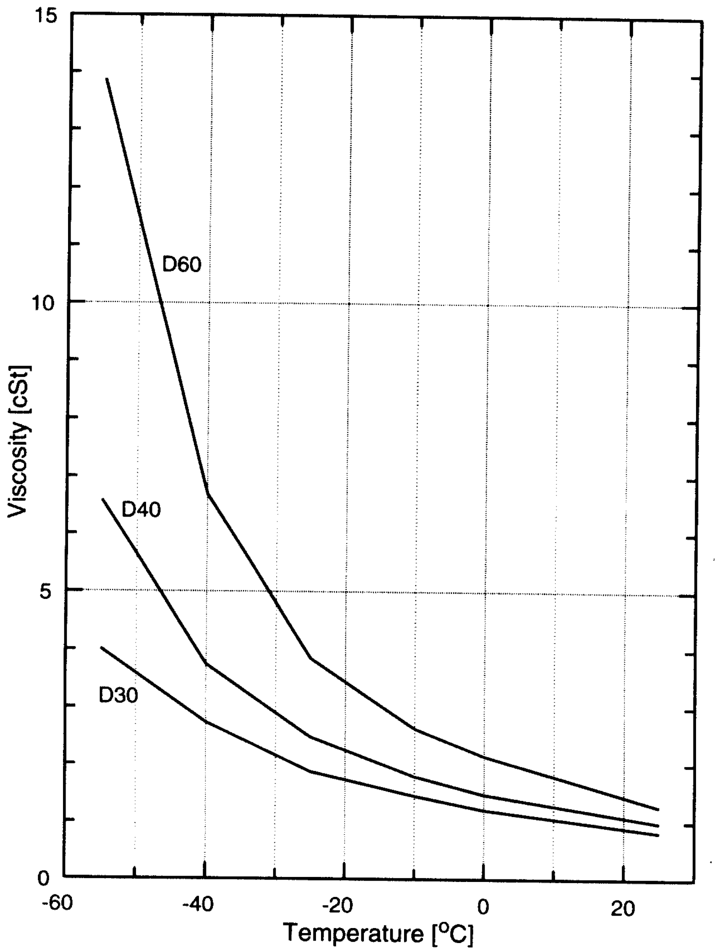

Fig. 4. Viscosity of three Exxon hydrocarbon liquids considered as primary borehole filler.

6. Conclusion

The drill hole fluid used in the GRIP drilling worked well; there were no adverse effects to either the drill or the drill operators. The liquid evaporated quickly from the core, and left a clean surface. Because this liquid is no longer available, a search for alternatives has indicated that a mixture of D60/HCFC-225 could be a possibility in the years to come, if further tests on HCFC-225 confirm the present available data.

Acknowledgment

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