DCE/GINR review and recommendations on regulation of drilling additives in relation to mineral exploration drilling in Greenland

Scientific note from DCE – Danish Centre for Environment and Energy and Greenland Institute of Natural Resources (GINR)

Date: 14 October 2024 | **55**

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Greenland Institute of Natural Resources

Data sheet

Scientific note from DCE – Danish Centre for Environment and Energy &
Greenland Institute of Natural Resources (GINR)

Category: Scientific briefing

Title: DCE/GINR review and recommendations on regulation of drilling additives in relation to mineral exploration drilling in Greenland

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Claimant: Environmental Agency for Mineral Resources Activities (EAMRA), Government of Greenland, Nuuk.

Please cite as: Bach, L, Fritt-Rasmussen, J, Jia, Y. 2024. DCE/GINR review and recommendations on regulation of drilling additives in relation to mineral exploration drilling in Greenland. Aarhus University, DCE - Danish Centre for Environment and Energy, 23 s. – Scientific note no. 2024|55

Front page photo: Lis Bach

Number of pages: 23

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Preface

The use of drilling additives for mineral exploration in Greenland are regulated based on the properties of the additives itself or the individual compounds in the drilling additives. However, often information on ecotoxicology, biodegradability, and bioaccumulation or even information on the individual compounds of the products is lacking.

By contract of date 30 May 2023, the Environmental Agency for Mineral Resource Activities (EAMRA) requested the Danish Centre for Environment and Energy (DCE) and Greenland Institute of Natural Resources (GINR) to provide:

1. A literature review on existing knowledge of drilling additives used in Greenland in relation to environmental impacts and ecotoxicology.
2. Recommendations for future evaluation and regulation of drilling additives in relation to mineral exploration and exploitation drilling.
3. A supplement to the BMP Rules for Fieldwork and Reporting to enhance transparency of the environmental assessment of drilling additives.
4. A comprehensive list of drilling additives that has been applied for in Greenland between 2017-2022 including information on the available data and the ability of conducting environmental assessments based on the available information.

The present note presents DCE/GINR input to that request.

1 Introduction

When conducting mineral core drillings/diamond drillings, chemical additives are often needed in the base fluid to enhance the performance and properties of the base fluid, i.e. density, viscosity, and other relevant parameters, thereby optimizing the drilling performance e.g. help improve drilling efficiency, wellbore stability, hole cleaning, lubricity, fluid loss control, and carry drill cuttings to surface.

In the present note, *drilling fluid* is defined as the liquid injected to the bore hole during drilling. The drilling fluid is a mixture of water and drilling additives. A *drilling additive* (often just mentioned additives hereafter) is a product, that is mixed with water to modify specific properties of the drilling fluid (as described in the upper section). *Drilling mud* is the mixture of the drilling fluid and rock (drill cuttings) resulting from the drilling process.

1.1 Environmental aspects related to drilling additives.

The drilling additives used in drilling fluids may have undesired environmental properties as high ecotoxicity, accumulation potential in biota and/or being non-biodegradable (Figure 1). Without adequate regulation, the use of drilling additives can lead to environmental concerns. Not all drilling additives may cause impacts to the environment and the market often holds less environmental hazardous products. The drilling additives encompass a variety of substances, including inorganic heavy metals, salts, polymers, oils, lubricants, and other contaminants. The products may hold impurities such as mercury as well as other heavy metals in bentonite, unpolymerized monomers of polymers, which may need special attention.

Undesired environmental properties of drilling additives

Ecotoxicity: Some drilling additives may be toxic to aquatic life and soil organisms.

Accumulation in biota: Some additives may accumulate in biota (organisms) over time, potentially affecting entire ecosystems.

Non-biodegradability: Non-biodegradable additives persist in the environment, posing long-term risks to biota.

Figure 1. Description of undesired environmental effects of drilling additives.

Proper disposal of drilling mud is essential, considering its potential impact on environment and biota. Excess drilling fluid brought to the surface during drilling operations may if discharged onto the terrain, adversely impact local ecosystems and potentially contaminate freshwater systems. The presence of drilling mud in the terrain can compromise soil quality due to high salt content, heavy metals, and/or organic compounds, leading to alterations in soil structure, nutrient availability, and microbial activity, thereby impacting plant growth and overall ecosystem health. If drilling mud enters freshwater systems, it can result in elevated contaminant levels, oil sheen, pH alterations, and increased turbidity,

posing threats to aquatic life by causing ecotoxicity, oxygen depletion, and habitat degradation.

Responsible use and disposal of drilling fluids and drilling mud necessitates comprehensive risk assessment and adherence to best practices, to fulfill both drilling requirements and environmental protection. Mitigation strategies to minimize environmental hazards include proper recycling of drilling fluids and substitution of harmful additives. A trend is shifting towards employing vegetable oils rather than fossil hydrocarbons as lubricants, and more broadly, towards the utilization of biodegradable and less environmental hazardous additives.

1.2 Aims of the present note

This note presents a literature review on drilling additives and their ecotoxicological properties in an Arctic terrestrial environment in relation to mineral exploration activities. Information on the regulation of the use of drilling additives in relation to exploration drilling in in other Arctic/Nordic countries is also included.

Defined aims of the project behind this note are to provide:

1. A literature review on existing knowledge of drilling additives used in Greenland in relation to environmental impacts and ecotoxicology.
2. Recommendations for future evaluation and regulation of drilling additives in relation to mineral exploration and exploitation drilling.
3. A supplement to the BMP Rules for Fieldwork and Reporting to enhance transparency of the environmental assessment of drilling additives. This includes a flowchart outlining the evaluation process for these drilling additives.
4. A comprehensive list of drilling additives that has been applied for in Greenland between 2017-2022 including information on the available data and the ability of conducting environmental assessments based on the available information.

The methodology applied for this note is described in Appendix 2.

2 Regulation of drilling additives in Greenland

In Greenland, exploration drilling operations including the use of drilling additives are subject to approval by the Governments Bureau of Minerals and Petroleum (BMP) (BMP 2000, Rules for Field Work, §4, see Figure 2).

The mining companies must submit an application for field activities, including drilling, to the authorities (https://govmin.gl/exploration-prospecting/start-exploring/field-activities/). The application includes among other things a detailed list of drilling additives to be used, the expected amounts of the product to be used and safety data sheet (SDS) or material safety data sheet (MSDS)[1] for each product. The applicant must also describe whether recirculation will be applied, and how the drilling mud and excess drilling fluid are handled and disposed of after drilling.

The requirements for the use of drilling additives set in §4.04.04 and §4.04.05 (BMP 2000) are based on an overall evaluation of the specific concentrations, amounts and ecotoxicological, bioaccumulation and degradation properties for each product. Often, however, the information and data necessary to perform an assessment of the drilling additives are not provided. In such cases, The Environmental Agency for Mineral Resource Activities (EAMRA) requests the company to provide detailed information on ecotoxicology for the drilling additives. However, often with only limited success because the companies are unable to get the information from their supplier or manufacturer because the information is considered confidential as it is of commercial value. The actual environment for the specific application is taken into consideration in the assessment of the drilling additives. In general, in Greenland, it is advised by DCE/GINR that there is a minimum of 100 meters to lakes and major freshwater streams from the drilling activity.

1) MSDS (Material Safety Data Sheet) was the original system for providing information about the properties of chemical products, whereas SDS is the updated system that conforms to international standards. In comparison to SDS, MSDS was less standardized and could have many different formats.

4. Diamond drilling and other drilling operations

4.01. General matters

4.01.01. Chapter 4 comprises those special provisions which, in addition to the general provisions in chapter 1 and possible additional provisions in chapter 2-3, apply to diamond drilling and other drilling operations. Additional provisions may be laid down at BMP's approval of the specific drilling operations, cf. subchapter 4.02.

4.02. Approval of drilling operations

4.02.01. Diamond drilling and other drilling operations are subject to BMP's approval.

4.02.02. For approval of drilling operations the application form in enclosure 4.01 shall be forwarded to BMP, filled in for all sections, if possible not later than 1 month before the drilling operations are commenced. Additional information will be required in case of drilling operations through ice, in lakes, streams and at sea, and approval of such operations will in most cases include special provisions.

4.03. Drilling equipment

4.03.01. Drilling operations shall be carried out with non-selfpropelled drilling equipment, unless otherwise approved by BMP.

4.03.02. Transmissions and other mechanical moving parts of the drilling equipment shall be adequately shielded.

4.04. Drilling operations

4.04.01. Excavation work as part of drilling operations may be carried out, provided the soil and surface is reestablished after the operations.

4.04.02. During drilling operations and moving of drilling equipment, the crew shall wear hard hats and safety footwear. During drilling operations earplugs shall also be used. Dust masks and goggles shall be worn if drilling operations are carried out without drilling fluid.

4.04.03. During drilling operations first aid equipment and a frost proof hand-operated fire extinguisher of a suitable size shall be placed at the drilling site. At least one person in each team shall be instructed in basic first aid and in the use of the first aid equipment.

4.04.04. Only water with an admixture of nontoxic drilling fluid additives shall be used unless BMP approves otherwise.

4.04.05. BMP may demand that the drilling fluid is recirculated and recycled to the greatest possible extent.

4.04.06. If water under pressure is encountered in the hole during drilling operations, the hole shall be sealed so that outflow of water is prevented.

4.04.07. Cuttings and other materials, apart from cores, which are not kept as samples, shall be smoothed out at the drilling site.

4.04.08. When drilling operations have been concluded, the drill holes shall be plugged and marked with an unequivocal weatherproof identification.

Figure 2. Rules for use of drilling additives listed in §4.01 - 4.04 in 'Rules for field work and reporting regarding mineral resources (excluding hydrocarbons) in Greenland', (BMP 2000).

3 Literature review on drilling additives

The methodology applied for literature search is described in Appendix 2. The literature search in the bibliographical databases (ISI Web of Science Core) did not provide hits on drilling additives used in Arctic land-based mining explorations. No hits were found on the tradenames of the most applied drilling products either. No studies on ecotoxicology of drilling additives were found for the terrestrial Arctic. A search on Google provided two matches. One Canadian master thesis report (Wilson 2003) on drilling additives where drilling took place on Arctic lake ice. In the thesis it was noted that no literature existed on the topic of ecotoxicology of drilling additives. The effects of the drilling mud and excess drilling fluid to water quality, sediment quality, and benthic biota was explored in practical studies. Based on these it was concluded that '*One year after effluent release there were no detectable differences in the benthic invertebrate population when compared to pre-release*' and that '*Numbers of individuals and species richness dropped right after drilling but had rebounded one year later*' (Wilson 2003). The study further concluded that effects on biota and seafloor from drilling additives were minor.

The other report provided from a Google search was an Irish report, with the objectives to '…develop guidance documents for screening for Appropriate Assessment of the potential environmental impacts of certain mineral exploration methodologies…' (Gordon et al. 2017). The report concluded that '*the assessments have found that no significant effects on the environment are likely to result from Diamond Drilling, Reverse Circulation Drilling and Portable Drilling as mineral exploration methodologies, providing that identified appropriate standard operating procedures are adopted and in line with EMD* (Exploration and Mining Division of the Department of Communications, Climate Action and the Environment) *guidelines*' (Gordon et al. 2017).

The literature search did not provide useful information on environmental aspects of drilling additives. In contrast, literature on drilling additives in the Arctic related to oil and gas exploration/exploitation drilling was found in large numbers. The higher level of attention on oil and gas related drilling additives in the scientific literature, is probably related to the amounts of drilling fluids, magnitudes higher, used and disposed of in oil and gas drilling compared to the mineral core exploration drilling. There might, however, be an overlap in some constituents in the products used between oil and gas drilling and mineral core drilling, as the function of the drilling additive as lubricant is the same while the additives in oils and gas drilling also have important key functions in relation to regulation of pressure (density and gas absorption).

4 List of drilling additives applied for in Greenland in 2017-2022

A list on the drilling additives applied for in relation to mineral core drilling in Greenland between 2017-2022 has been prepared. The table is presented in Appendix 1 in this note. The table provides the tradename and supplier of the product as well as available information on ecotoxicology, biodegradability, bioaccumulation and ingredients provided in the SDS. The products are colour coded based on whether essential information is available for an environmental risk assessment and if the products can be environmentally evaluated. The list is not intended as a 'positive list' but could be used as inspiration for the companies in the process of selecting drilling additives. It should be kept in mind that less hazardous products are entering the market thus the green products on the list, is not necessarily the Best Available Technology (BAT) or Best Environmental Practices (BEP) option for future drilling activities.

5 Regulation of drilling additives in Arctic and Nordic countries

Environmental authorities in Canada, Alaska, Norway, Finland and Sweden as well as Denmark were consulted regarding the regulation of drilling additives. Below is a summary of the received information.

5.1 Canada

The relevant Canadian regulation that provides supervision regarding the handling and regulation of drilling mud is the 'Metal and Diamond Mining Effluent Regulations'[2], which fall under the Fisheries Act. Quite many details are given in the regulation. For the full detailed picture, the regulations can be consulted[3].

Drilling additives are not described separately, but rather described in more general terms e.g. 'effluent containing any deleterious substance'. According to the Metal and Diamond Ming Effluent Regulations, the effluent generating from mining activities must meet concentration-based limits for arsenic, copper, cyanide, lead, nickel, zinc, suspended solids, radium 226 and un-ionized ammonia. Effluent must also have a pH that is between a minimum and maximum level and must not be acutely lethal. The regulations require effluent testing and reporting, as well as Environmental Effects Monitoring studies.

5.2 Alaska

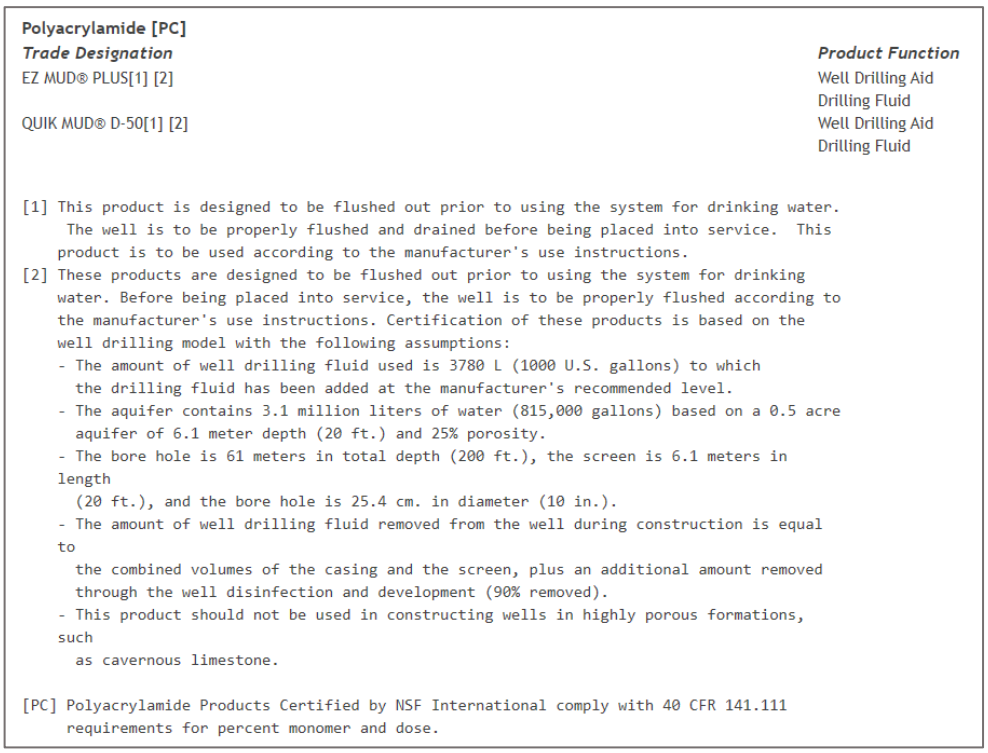
The Alaska Department of Natural Resources (DNR) adhere to the American National Standards Institute (NSI) regulations on drinking water wells, i.e. if the mud is NSI 60 or 61 certified it is safe for use in drinking water wells and thus also for diamond drilling in mineral exploitation activities. The certification can be found directly on the SDS, but if the information is lacking, the DNR can look it up in a database (NSF Product and Service Listings; Listing Category Search Page | NSF International). The overarching aim of the NSF 60 or 61 certification is to protect humans from contaminants from the water supply. DNR requires that no drilling additives enter streams or lakes (as most drilling additives are bentonite based and might course sediment over spawning beds, etc.).

The regulation in NSF is based on an extensive review of toxicology data to humans (described in NSF/ANSI/CAN 600 – 2023 Health Effects Evaluation and Criteria for Chemicals in Drinking Water). Some of the drilling additives applied for use in Greenland appear on the NSF Product and Service Listings. An example of a drilling additive on the NSF Product and Service list is presented in Figure 3. For the example below for the product 'EZ-MUD/QUIK MUD' it is stated in the database that the additive(s) must be flushed out of the system prior to using the well for drinking water.

The intention of the regulation of drilling additives in mineral exploration in Greenland is to safeguard the environment. Opposite to the Greenland regulation the NSF regulation is designed to protect the drinking consumer but without considerations for the surrounding environment. This difference makes the NSF regulation on drinking water wells difficult to directly transfer to the

[2] Metal and Diamond Mining Effluent Regulations (justice.gc.ca)
[3] https://laws-lois.justice.gc.ca/eng/regulations/SOR-2002-222/index.html

Greenland environmental regulations on mineral exploration. The human ecotoxicology data used for the NSF regulation might not reflect the toxicity to the invertebrates and algae species, that might be more sensitive than humans to some additives. And importantly, while a compound should be efficiently flushed out (as stated in the example in [1] in Figure 3) in relation to drinking water and humans, it may cause effects in the receiving environment.



Polyacrylamide [PC]

Trade Designation	*Product Function*
EZ MUD® PLUS[1] [2]	Well Drilling Aid Drilling Fluid
QUIK MUD® D-50[1] [2]	Well Drilling Aid Drilling Fluid

[1] This product is designed to be flushed out prior to using the system for drinking water. The well is to be properly flushed and drained before being placed into service. This product is to be used according to the manufacturer's use instructions.

[2] These products are designed to be flushed out prior to using the system for drinking water. Before being placed into service, the well is to be properly flushed according to the manufacturer's use instructions. Certification of these products is based on the well drilling model with the following assumptions:
- The amount of well drilling fluid used is 3780 L (1000 U.S. gallons) to which the drilling fluid has been added at the manufacturer's recommended level.
- The aquifer contains 3.1 million liters of water (815,000 gallons) based on a 0.5 acre aquifer of 6.1 meter depth (20 ft.) and 25% porosity.
- The bore hole is 61 meters in total depth (200 ft.), the screen is 6.1 meters in length (20 ft.), and the bore hole is 25.4 cm. in diameter (10 in.).
- The amount of well drilling fluid removed from the well during construction is equal to the combined volumes of the casing and the screen, plus an additional amount removed through the well disinfection and development (90% removed).
- This product should not be used in constructing wells in highly porous formations, such as cavernous limestone.

[PC] Polyacrylamide Products Certified by NSF International comply with 40 CFR 141.111 requirements for percent monomer and dose.

Figure 3. Example of a description in the NSF Product and Service Listings of a typical applied product in Greenland (Listing Category Search Page | NSF International).

5.3 Norway

According to the legislation on pollution (Forurensningsloven, Forskrift om begrensning av forurensning (forurensningsforskriften) – Lovdata[4]), it is prohibited to pollute. Hence, mining industry needs specific permissions to discharge in compliance with the legislation (Forurensningsloven). Information about the additives used in the drilling process is in principle necessary input in the application for the permission. However, from the contact in the Miljødirektoratet (by email) it is understood that since very little additives are being used in land-based core drilling activities, it is not regulated specifically.

Three focus points are related to the permission for discharge: the use of BAT (Best Available Technology), reduction of the pollution, and possible substitution of chemicals[5].

[4] Forurensningsloven, Forskrift om begrensning av forurensning (forurensningsforskriften) – Lovdata Lov om vern mot forurensninger og om avfall (forurensningsloven) - Lovdata

[5] https://miljoringen.no/wp-content/uploads/2017/06/Dag-1-14-Kari-Kjonigsen.pdf)

The Norwegian regulation of specific chemicals can be looked-up at a web-page by use of CAS-numbers: Kjemikaliesøk – Miljødirektoratet (miljodirektoratet.no).

5.4 Finland

No information on environmental assessment of drilling additives could be obtained from Finland.

5.5 Sweden

The 'Bergsstaten' (Mining Inspectorate of Sweden) is responsible for issuing permits for exploration and mining. Mineral Exploration is permitted by the 'Minerallagen' (Minerals Act 1991: 45[6]) and to actually complete the exploration fieldwork a work approval is also needed (arbetsplan,[7]). 'Prøvebrydning' is regulated by the 'Miljöbalken'[8]. A close survey of Swedish Environmental Protection Agency (SEPA) and Geological Survey of Sweden (SGU) does not provide useful information in relation to the use and environmental impact of drilling fluids/additives in relation to mining activities in Sweden. On the results obtained it is not clear how drilling additives in particular are regulated. 'Förordning (2013:319) om utvinningsavfall' (translates to: Regulation on mining waste), § 40 describes if there is a lack of information that is necessary for the characterization of the waste, a sampling plan must be established according to the standard SS-EN 14899:2005 and samples should be taken according to the sampling plan and testing carried out. In § 41 it describes that the sampling plan according to § 40 must be based on the information that has been identified for the purpose of the plan in terms of among other samples from drill cores.

By contacts to the 'Swedish Mining Inspectorate', further information describes that there is no direct list to of what drilling additives that can be used. The contact further describes that 'the environmental issues surrounding exploration are governed partly by the Minerals Act, which more generally states that 'The work must be carried out in such a way that the least damage and intrusion is caused to someone else's property and to the natural and cultural environment.' Otherwise, the Environmental Code applies and the supervisory authority is the municipality or county administrative board depending on the nature of the work. SweMin has compiled a guide[9] in which chapter 6.6 and especially 6.6.7 deals with risks in exploration, particularly chemicals, oils and fuels. Drilling chemicals are mentioned in 6.6.7.2, and they should primarily be as environmentally friendly as possible and be approved by the client. A list of chemicals, including safety data sheets, must be available at the drilling site if the chemicals are classified as hazardous.' Further, in chapter 6.6.7.2. it states that any residues of drilling chemicals must be collected and disposed of. Alternative drilling additives that pose less risk to the environment should be prioritized. This includes products that degrade quickly or otherwise comply with environmental standards.

[6] Mineral Act (1991:45) (sgu.se)
[7] https://www.sgu.se/bergsstaten/prospektering/arbetsplaner-och-undersokningsarbete/
[8] https://www.riksdagen.se/sv/dokument-lagar/dokument/ svensk-forfattningssamling/miljobalk-1998808_sfs-1998-808
[9] prospvgl_sve_v11-lgupplst.pdf (triggerfish.cloud)

5.6 Denmark

In Denmark, drilling for raw minerals is regulated according to the 'Råstofloven'. But in Denmark, most drilling is related to water supplies, tunnels, and other underground passages. For those purposes and with potential for contamination of groundwater in case of spill, the drilling additives are regulated according to mobility, solubility, ecotoxicity, bioaccumulation potential and degradation properties as well as the Danish EPA 'Jordkvalitetskriterier' (DHI, 2022). The same assessment criteria are being used in risk assessment for drilling additives for shale-gas production and fracking (Hjort et al., 2016). According to HOFOR (2022), the drilling addtives for water supply drillings are regulated according to the NSF61 certification system (see above section 5.2).

5.7 Summary of regulation in other countries

Based on the insights gained from the Arctic/Nordic countries consulted in this project, DCE/GINR conclude that drilling additives are either regulated under a common practice that there must be no pollution, or they are regulated under the NSI 60 or 61 classification system for drinking water wells. The review of regulation in these countries is however limited by very complex administrative structures; hence, it is likely that we have not succeeded in acquiring all the relevant information within the frame of this project.

Overall, DCE/GINR recommend that an environmental risk assessment of each specific drilling additives should be conducted. DCE/GINR assess that implementing the NSF 60 certification might not be adequate for the purpose of environmental protection for some additives and areas, at least for the described practice where excess drilling fluid and mud often is discharged to the ground.

6 Flowchart on environmental assessment of drilling additives

The process used to environmentally assess the drilling additives has been illustrated in a flowchart to make the regulation objectives of drilling additives evident for the applicants in Greenland. Thereby, the applicant can become familiar with the assessment criteria that are required from the authorities to be able to complete the environmental assessment of the drilling additives prior to permission.

The flowchart (Figure 4) provides an overview of the information necessary to perform an environmental assessment of drilling additives. The flowchart is developed inspired by the 'OSPAR Recommendation 2010/4 on a Harmonized Pre-Scheme for Offshore Chemicals'. The assessment is based on the ecotoxicological properties of the drilling additives, including the toxicity to organisms, whether the product bioaccumulates or not, and the ability of the product to degrade in nature. The assessment is preferably conducted on ecotoxicological data provided in the product safety data sheet (SDS) provided for the drilling fluid. In cases where this information is not available, the assessment could be performed based on information of all chemical ingredients of the product (adding up to 100% of the additive). In this case, it is essential that the CAS number of each ingredient is provided. The retailer or the producent could be further contacted to provide the information not found in the SDS. If needed, the information on chemical composition and/or ecotoxicology data can be held confident. The drilling additive may be listed in the Danish Product Registry[10], PROBAS, or other relevant product registries as REACH[11], OSPAR PLONOR[12] list or similar registries with an environmental assessment. If the product is listed in any of the mentioned registries, the essential data needed to conduct the environmental assessment would be available in the registry.

[10] The Danish Product Register, PROBAS, is a governmental data base for information and evaluations concerning substances, materials and products used in Denmark.
[11] REACH is a European Union regulation that stands for Registration, Evaluation, Authorisation, and Restriction of Chemicals. It aims to manage and control the risks associated with chemical substances by requiring companies to register, evaluate, and, if necessary, authorize or restrict the use of certain substances to protect human health and the environment.
[12] The PLONOR list is a list of chemicals the OSPAR commission considered to pose little or no risk to the environment.

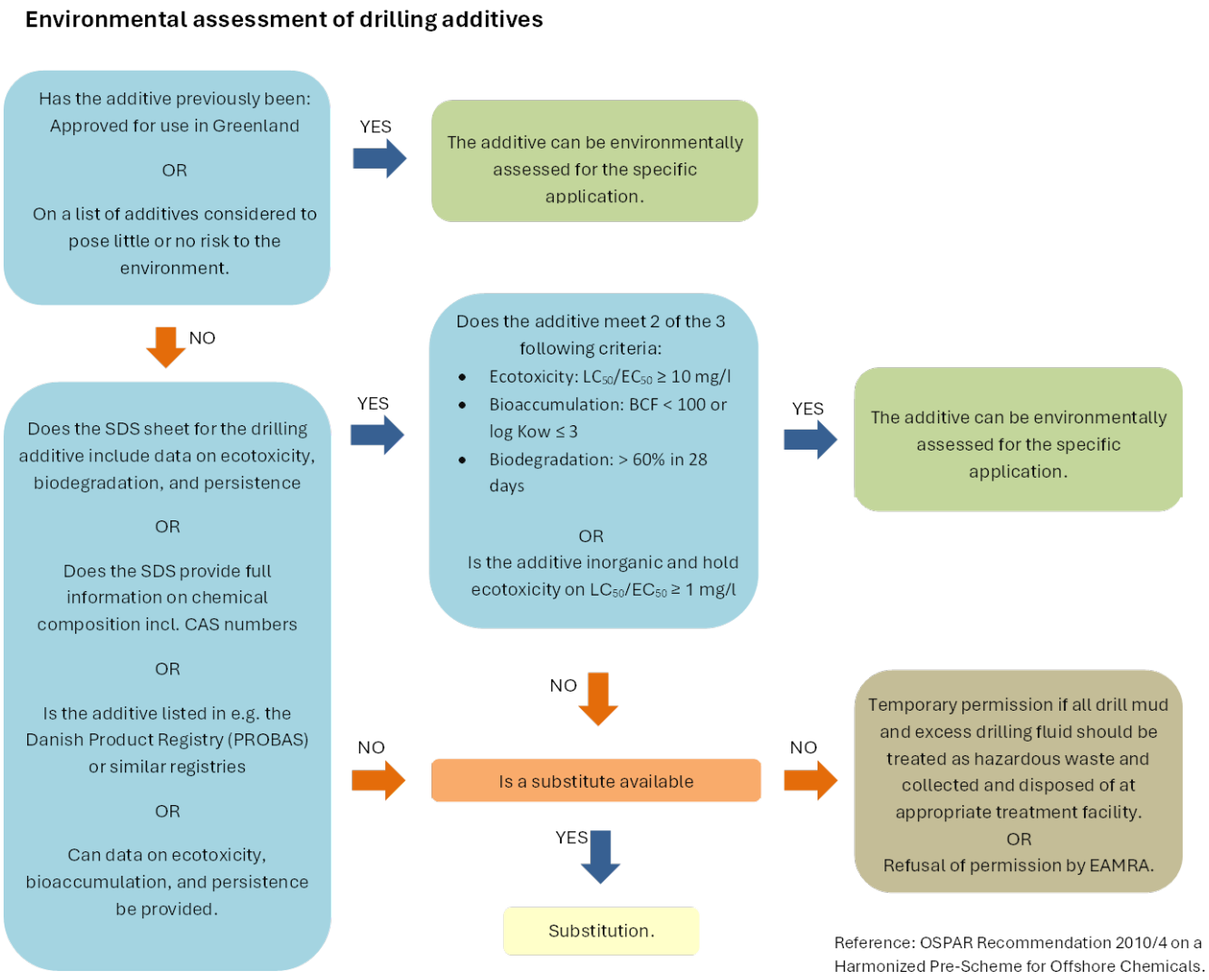


Figure 4. Flowchart of the environmental assessment objectives of drilling additives used for drilling activities in Greenland.

The environmental assessment has four outcomes:

1. Based on available data, a positive environmental assessment can be conducted if EAMRA and its environmental consultants conclude that there are no case specific conditions against it.
2. Based on available data, the drilling additive should be substituted with a less environmentally hazardous alternative.
3. Based on available data, temporary permission can be given provided that residues from the drilling, i.e. drilling mud and excess drilling fluid, are treated as environmental hazardous waste and collected for designated disposal at a receiver station.
4. Based on available data, the drilling additive is deemed potentially environmentally hazardous, and no substitute product exists. If the surrounding environment is sensitive, such as being in proximity to freshwater systems or containing red-listed organisms, and collection of drilling mud and excess of drilling fluid are impractical, the permission to use the drilling additive cannot be authorized.

7 Recommendations for evaluation of drilling additives

Based on acquired knowledge in the present project and previous and existing procedures, DCE/GINR have listed a number of recommendations regarding the use of drilling additives.

1. DCE/GINR recommend that drilling is performed to the greatest extent possible with water-only and without drilling additives.
2. DCE/GINR recommend that in cases where water-only is not applicable, non-toxic drilling additives can be used upon approval by authorities.
3. DCE/GINR recommend that less environmental hazardous and water-based drilling additives are preferred over oil based. Also, vegetable oils should be preferred over fossil hydrocarbon-based oils as lubricants.
4. DCE/GINR recommend that the approval of drilling additives by the authorities are regulated according to the amounts, components, concentrations, water mixing ratio, ecotoxicological properties, biodegradability, bioaccumulation and the sensitivity of the surrounding environment (See also flowchart in Figure 4).
5. DCE/GINR recommend that drilling additives are compliant with REACH.
6. DCE/GINR recommend that there is a minimum of 100 meters to lakes and major fresh-water streams from the drilling activities using additives.
7. DCE/GINR recommend that the drilling additives are recirculated and recycled to the greatest possible extent.
8. DCE/GINR recommend that drilling mud and excess of drilling fluid are backfilled into the drill holes or collected and disposed of in an approved treatment facility to avoid environmental hazard.
9. DCE/GINR recommend that the flowchart (Figure 4) is made available for the applicants, for example as an appendix to the BMP Rules for field work and reporting (BMP 2020).
10. DCE/GINR recommend that the list of previously assessed drilling additives is evaluated periodically in accordance with Best Available Technology (BAT) and best environmental practice (BEP).
11. DCE/GINR recommend that special care is taken to prevent spills during handling and transport of the drilling additives. It is recommended that a remediation plan should be prepared in advance in relation to leakage and accidental spills. If leakage or spills occurs, the company is obliged to report to authorities immediately.
12. DCE/GINR recommend that proper storage of drilling additives is required to prevent it from spilling with subsequent impacts on the environment. It is recommended to store it under roof/cover in containment berms, preferably containerized. Especially during winter, safe storage should be taken into consideration as plastic buckets may become fragile in the low arctic temperatures.

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Appendix 1 – Drilling additives applied in Greenland (2017-2022)

Drilling additives previously applied for in Greenland (2017-2022) with indications of level of information (Y=Yes the information is available or N=No information available) needed for environmental evaluation.

DRILLING ADDITIVE NAME	PRODUCER OR SUPPLIER	MSDS/SDS PROVIDED	ECO TOXICOLOGY DATA	PERSISTENCE DATA	BIOACCUMULATION DATA	CAS NO	FULL INFO ON INGREDIENTS	PARTLY INFO ON INGREDIENTS	COLOR CODE
PAM C-400 Series Polymer	ClearTech Industries Inc.	Y	Y	Y	Y	Y	Y	Y	1
CON DET®	Halliburton	Y	Y	Y	Y	Y	N	Y	1
EZ-MUD® (EZ MUD®)	Halliburton	Y	Y	Y	Y	Y	N	Y	1
Thread Save Eco Grease - Kopr-Kote	Jet - Lube	Y	Y	Y	Y	Y	N	Y	1
LRMUD-7	Rantec Corporation	Y	Y	Y	Y	N	N	N	1
1) Synvis D 2) MPP Gold Dust Standard Dry Polymer – Di-Corp SYNVIS D	1) Di-Corp 2)	Y	Y	Y	Y	N	N	N	1
Multimix	Diversity Technologies Corp. (Di-Corp)	Y	Y	Y	Y	N	N	N	1
Extreme Alkamer	EXTREME	Y	Y	Y	N	Y	N	Y	2
Alcomer 110 RD	NOV FluidControl	Y	Y	Y	N	Y	N	N	2
AMC CR-650 (CR-650 Core recovery Polymer)	AMC	Y	Y	Y	N	N	N	Y	2
Ultracut 370plus	Rocol	Y	Y	N	N	Y	N	Y	2
Torqueless	g) Matex-Fordia; Control Chemical Corporation	Y	Y	N	N	N	N	N	2
Linseed soap	AMC, Fordia or Time	Y	N	Y	N	N	Y	Y	2
AMC Bentonite PLUS	AMC	Y	Y	N	N	Y	Y	Y	3
DRTG ZN50	AMC	Y	Y	N	N	Y	Y	Y	3
Sodium chloride (NaCl, Natrium klorid)	Chemicals & Laboratory Equipment-Sci lab	Y	N	Y	N	Y	Y	Y	3
Big Bear Rod Grease	DICORP	Y	N	N	N	Y	Y	Y	3
HadraCap XP	Scomi Oiltools	Y	N	N	N	Y	N	Y	3
Ultravis	Matex	Y	N	N	N	Y	N	Y	3

DD 2000	Matex, Control Chemical Corporation	Y	N	N	N	Y	N	N	3
Sand-Drill	Control Chemical, Matex-Fordia	Y	N	N	N	N	Y	Y	3
DD1200 (DD 1200 Viscosifier)	Matex	Y	N	Y	N	Y	N	Y	4
VULTREX DRILL ROD HEAVY	Petro-Canada Lubricants	Y	N	N	N	Y	N	Y	4
API Modified Thread Compound	Petro-Canada	Y	N	N	N	Y	N	Y	4
AMC Liqui POL	AMC	Y	N	N	N	N	N	Y	4
Bio-DDR Grease	Robco Inc.	Y	N	Y	N	N	N	N	5
Bio Black Widow	Manucacturer: Robco Inc Supplier: Fordia	Y	N	N	N	N	N	N	5
DD X-Pand Coarse	Matex	Y	N	N	N	N	N	N	5
G-Stop	Matex, Diversity Technologies Corp. (Di-corp)	Y	N	N	N	N	N	N	5
Hi-Viz	DUCO	Y	N	N	N	N	N	N	5
Plug Control	DUCO	Y	N	N	N	N	N	N	5
REIFLOCK A 63	REIFLOCK, SNF Health-Safety Environment	Y	N	N	N	N	N	N	5
MPP DRG-XT Rod Grease – Extreme rod grease	EXTREME	Y	N	N	N	N	N	N	5
MPP DRG-XT Rod Grease – Extreme rod grease	EXTREME	Y	N	N	N	N	N	N	5
Thread compound (copper grease)	Not available in the field report	N	N	N	N	N	N	N	5
AMC Bentonite HV	AMC	N	N	N	N	N	N	N	5
Ezyfoam	Not available	N	N	N	N	N	N	N	5

1 Contains necessary information => The product can be evaluated.

2 Contains most important information => The product can in most cases be evaluated.

3 An evaluation can be conducted on the individual ingredients of the drilling additive. The 100 % detailed information on ingredients (products/chemicals) contained in the drilling additive is provided.

4 An evaluation can be conducted on the individual ingredients of drilling additives. The 100% detailed information on ingredients (products/chemicals) contained in the drilling additive is NOT provided, and the assessment might not be valid.

5 No information on the drilling additive is provided => The drilling additive cannot be assessed.

Appendix 2 - Methodology

Literature review on drilling additives:

To obtain information on ecotoxicological information on drilling additives, a systematic literature search has been conducted in bibliographical databases (ISI Web of Science) and popular search engines such as Google. The search operators AND and OR were used for multiple searches, to combine search terms in different ways. Asterisks were used as wildcard symbol, representing any character within a word. 'Snowballing' was also applied, by assessing the references in the gained literature for further literature not caught in the systematic searches. The searches were focused on words as mine, mining, drill*, Arctic, additive, tox*, terrestrial, etc. Table 1 shows the used systematic search strategy, including search terms (bold) and search operators (AND/OR). Specific tradenames of a number of products were also searched for.

Table 1. Overview of the systematic search strategy, including search terms (bold) and search operators (AND/OR). *used as wildcard symbol.

Literature search in ISI Web of Science						
Mine*	AND	Drill*	AND	Arctic	AND	Chemical*
Mining*	AND	Drill*	AND	Arctic	AND	Chemical*
Mine*	AND	Drill*	AND	Arctic	AND	additive*
Mining*	AND	Drill*	AND	Arctic	AND	additive*
Mine*	AND	Drill*	AND	Arctic	AND	fluids
Mining*	AND	Drill*	AND	Arctic	AND	fluids
Arctic	AND	Tox*	AND	Drilling additive*		
Drilling additives	AND	Tox*	AND	terrestrial*		
Additive*	AND	Tox*	AND	mining	AND	Arctic
Land-based Drilling*	AND	Tox*				
Land-based Drilling*	OR	Land based drilling*	AND	Tox*		
Mine*	AND	Mining				
Drilling	AND	Drilling mud	AND	Drilling fluid		
Drilling fluid	AND	Guideline				
Drilling fluid	AND	Rule				
Drilling fluid	AND	Regulation				
Drilling fluid	AND	Act				
Drilling fluid	AND	Mining	AND	Review		
Drilling mud	AND	Guideline				
Torqueless	AND	Drill*				
EZ-Mud	AND	Drill*				
DD1200	AND	Drill*				
DD2000	AND	Drill*				

Regulation in other Arctic countries

Search engines as Google, as well as network contacts were approached to obtain information on the level and method of regulation in other Arctic/Nordic countries i.e., Canada, US (Alaska), Norway and Sweden. Contacts were also approached by phone or email.

Flowchart on the environmental evaluation of drilling additives

A flowchart providing detailed information on the different steps in environmental evaluation and what information is needed was developed based on existing guidelines and principles for evaluating chemicals (OSPAR Recommendation 2010/4).

List of drilling additives applied for in Greenland in 2017-2022

A list of additives that companies have applied for in the latter 5 years was developed by reviewing previous 'Field applications' submitted to BMP and environmentally evaluated by DCE/GN. The submitted drilling applications were reviewed for the use of drilling additives and the attached SDS for the drilling additives were examined for availability of ecotoxicological data i.e., environmental toxicity, bioaccumulation and potential biodegradation. The list further provides information on whether an environmental evaluation of the additives was feasible based on the available information.