



REVIEW ON ENVIRONMENTAL RISK ASSESSMENT OF MINING CHEMICALS USED FOR MINERAL SEPARATION IN THE MINERAL RESOURCES INDUSTRY AND RECOMMENDATIONS FOR GREENLAND

Scientific Report from DCE - Danish Centre for Environment and Energy

No. 203

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Data sheet

Series title and no.:	Scientific Report from DCE – Danish Centre for Environment and Energy No. 203
Title:	Review on environmental risk assessment of mining chemicals used for mineral separation in the mineral resources industry and recommendations for Greenland
Authors:	Lis Bach, Rasmus Dyrmosø Nørregaard, Violeta Hansen & Kim Gustavson
Institution:	Aarhus University, Department of Bioscience
Publisher:	Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL:	http://dce.au.dk/en
Year of publication:	2016
Editing completed:	September 2016
Referee:	Jakob Strand
Quality assurance, DCE:	Vibeke Vestergaard Nielsen
Financial support:	The Environmental Agency for the Mineral Resources Area, EAMRA, Greenland
Please cite as:	Bach, L., Nørregaard, R.D., Hansen, V. & Gustavson, K. 2016. Review on environmental risk assessment of mining chemicals used for mineral separation in the mineral resources industry and recommendations for Greenland. Aarhus University, DCE – Danish Centre for Environment and Energy, 34 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 203. http://dce2.au.dk/pub/SR203.pdf
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Abstract:	<p>This report provides background knowledge that allows carrying out an environmental risk assessment of mining chemicals that expectedly will be used for separation of minerals in the future in the mining resource industry in Greenland. The Greenlandic environment is as other arctic areas particularly sensitive to contaminants. Therefore, the standard tests on mining chemicals performed under temperate conditions may require some adjustment, such as use of additional sensitivity factors, when applied for environmental assessments under arctic conditions.</p> <p>The general separation processes of minerals and the application of different types of chemicals are described. Further, the present review provides an environmental evaluation of selected mining chemicals that potentially may be applied in mineral separation processes in Greenland in the future. This is followed by a description of the regulatory framework for environmental risk assessment of chemicals in other relevant countries.</p>
Keywords:	Mineral extraction, mining chemicals, environmental management, Greenland
Layout:	Graphic Group, AU Silkeborg
Front page photo:	Lis Bach
ISBN:	978-87-7156-233-0
ISSN (electronic):	2245-0203
Number of pages:	34
Internet version:	The report is available in electronic format (pdf) at http://dce2.au.dk/pub/SR203.pdf

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Imaqarniliaq

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Sammenfatning

Denne rapport omhandler miljøvurdering af proceskemikalier som potentielt kan blive anvendt til ekstraktion af mineraler i fremtidige mineprojekter i Grønland. Grønlands miljø er som andre arktiske områder særligt følsomme over for forurening. Resultater fra standard laboratorie test af kemikaliernes nedbrydelighed, ophobning i organismer og giftighed kan ikke direkte anvendes til miljøvurderinger af kemikalier nedbrydelighed, ophobning i organismer og giftighed under arktiske forhold.

I denne rapport er de generelle separationsprocesser af mineraler og anvendelse af forskellige typer af proceskemikalier beskrevet. I rapporten er en række hyppigt anvendte proceskemikalier miljøvurderet. Dette er efterfulgt af en beskrivelse af de lovgivningsmæssige rammer for miljørisikovurdering af kemikalier i andre relevante lande. Rammerne for den miljørisikovurdering, som er gennemgået i denne rapport, er baseret på vurdering af de enkelte kemikaliers egenskaber med fokus på kemikaliernes PBT egenskaber, dvs. bionedbrydelighed (Persistens), evne til at blive ophobet i organismer (Bioakkumulering) samt giftighed (Toksicitet). Tilsvarende vurderingsramme anvendes i Den Europæiske Union (EU), Australien, Canada og USA. Det anbefales, at Grønland følger de samme principper ved miljøvurdering af kemikalier anvendt i mineindustri.

På nuværende tidspunkt skal alle minekemikalier og anvendelse af kemikalier som ønskes anvendt i et mineprojekt godkendes af de grønlandske myndigheder. Det anbefales, at denne praksis fortsættes. Det anbefales, at mineselskaberne skal indsende ansøgning om anvendelse af proceskemikalier i god tid før påtænkt anvendelse af kemikaliet. Ansøgningen bør indeholde en fuldstændig beskrivelse af de kemikalier, der ønskes anvendt, herunder detaljerede oplysninger om sammensætning af produkterne med CAS-numre. Data om toksicitet, bionedbrydelighed og potentiale for bioakkumulering skal foreligge. Ansøgningen skal også indeholde oplysninger om mængder af kemikaliet, der ønskes anvendt, samt nærmere oplysninger om dets kemiske og fysiske egenskaber. Desuden skal det beskrives, hvordan kemikaliet vil blive håndteret før og efter anvendelse, samt i hvilke koncentrationer og mængder det forventes at blive fundet i tailings, procesvand og spildevand. Det anbefales, at den indledende vurdering og regulering af minedrift kemikalier i Grønland baseres på de principper, der er beskrevet i konventionen om beskyttelse af havmiljøet i det nordøstlige Atlanterhav (OSPAR) og EU.

Der er generelt meget få oplysninger tilgængeligt om kemikaliers toksicitet, nedbrydning og biotilgængelighed under arktiske forhold. I tilfælde af usikkerhed, anbefales det at foretage supplerende 'arktiske' forsøg og undersøgelser.

Det anbefales, at der i den aktive fase af et mineprojekt samt ved nedlukning gennemføres et miljøprogram for at overvåge anvendelse af kemikalier og udslip af kemikalier til miljøet. Spildevand fra den mineralske forarbejdning og nedsivende spildevand skal overholde krav, som fastsættes af de miljøregulerende myndigheder.

Samlet set anbefales det, at alle aktiviteter, der involverer anvendelse af kemikalier i mineraludvinding skal overholde de bedste tilgængelige teknikker og bedste miljøpraksis.

Summary

This report provides background knowledge that allows carrying out an environmental risk assessment of mining chemicals that expectedly will be used for separation of minerals in the future in the mining resource industry in Greenland. The Greenlandic environment is as other arctic areas particularly sensitive to contaminants. Therefore, the standard tests on mining chemicals performed under temperate conditions may require some adjustment, such as use of additional sensitivity factors, when applied for environmental assessments under arctic conditions.

The general separation processes of minerals and the application of different types of chemicals are described. This is followed by a description of the regulatory framework for environmental risk assessment of chemicals in other relevant countries. The environmental risk assessment framework reviewed in this paper is based on an evaluation of the properties of the individual chemicals with focus on persistence, bioaccumulation and toxicity (PBT). Such a framework is used in the assessment methodology of European Union (EU), Australia, Canada and United States (US), and it is recommended that environmental risk assessment of mining chemicals to be used in Greenland follows the same principles.

At present, all mining chemicals and use of chemicals in the processing of minerals must be approved by the Greenlandic authorities. It is recommended that this procedure continues. Consequently, the mining companies have to submit an application in good time before the intended use of the chemical and the application must include a full description of the chemicals to be applied in the mining project, including detailed information on the composition of the products with CAS numbers. Data on toxicity, biodegradability and potential for bioaccumulation have to be provided and if such information does not exist, data on product ingredients must be made available. The application must also contain information on the proposed quantities of the chemical to be used and details on its chemical and physical properties and fate, including how the chemical will be managed and handled after its use and its concentrations and quantities in tailings, process water and drainage water. It is recommended that initial evaluation and regulation of mining chemicals in Greenland is based on principles for evaluation and regulation of chemicals in Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR) and EU.

Very little information on toxicity, degradation and bioavailability in arctic conditions is generally available. In case of uncertainties, supplementary "arctic" tests and studies must be conducted.

In the active phase of the mining and post-closure, an environmental programme must be implemented to monitor the use of chemicals and release to the environment. Effluents of mineral processing as well as drainage and seepage effluents must comply with requirements specified by the environmental regulatory authorities.

Overall, it is recommended that all activities involving use of chemical agents in mineral extraction should comply with the best available techniques (BAT) and best environmental practice (BET).

1 Introduction

The aim of this report is to provide background knowledge that allows carrying out environmental risk assessments of mining chemicals that will expectedly be used in the future in the mining resource industry in Greenland.

The mining companies are to describe the processes and the use of chemicals for mineral separation in the EIA according to the Guidelines for preparing an Environmental Impact Assessment (EIA) report for mineral exploitation in Greenland (MRA, 2015). Even though the EIA is approved, all mining chemicals for use in the processing of minerals need special permission by the Greenlandic authorities, Environmental Agency for Mineral Resources Activities (EAMRA), before actual application.

Mining chemicals are applied worldwide and are, in general, regulated environmentally as in others industries. However, application of chemicals in arctic mining processing may need specific environmental regulations adapted to the arctic conditions.

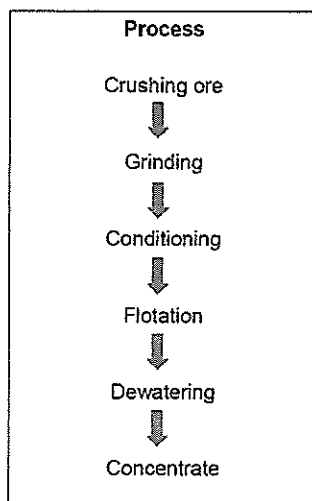
The Greenlandic environment is as other arctic areas particularly sensitive to contaminants (AMAP 1997). In the cold climate, many natural process rates are slower. Marine species may exhibit slower growth and mature at a later age; thus, the accumulation of chemicals within the organisms may take place over a longer time span. Furthermore, many arctic species contain more fatty tissue than temperate species from temperate climate zones, all factors that result in a higher potential for bioaccumulation of lipophilic contaminants. Chemicals may degrade more slowly at the lower arctic temperatures. As a consequence, the standard tests for mining chemicals performed under temperate climate conditions may need adjustment when applied for environmental assessment under arctic conditions, for instance by use of extra sensitivity factors.

In this document, we first describe the general separation processes of minerals and the different types of chemicals used. Secondly, we give an environmental evaluation of selected chemicals that potentially may be applied in the future mining processes in Greenland, followed by a review of the regulatory framework for environmental risk assessment of chemicals applied in other relevant countries. Finally, we provide recommendations for environmental regulation and risk assessment in Greenland.

2 Mineral separation processes

The initial step in mineral processing involves crushing and grinding of the ore to produce a particle size suitable for further processing using physical and chemical separation methods (Lottermoser, 2010; Hansen et al., 2016).

Figure 1. Schematic illustration of extraction processes for mineral separation.



Physical separation processes exploit the different physical properties of the mineral particles such as size, density, magnetic and surface energy and behaviour. Commonly used physical separation processes are: gravity concentration, magnetic separation and/or flotation separation, some of which include the use of mining chemicals.

Mining chemicals are widely used in the processing of minerals and separation of the valuable elements. In designing a treatment process, the selection of chemicals is a delicate process that is to ensure the most effective separation and concentration results.

Chemical separation processes involve leaching of one or more target minerals. Processes used for separation of individual metals are usually alkaline or acid leaching, but several other chemical processes for, for instance, purification and concentration may be applied.

This chapter will briefly describe the physical and chemical processes applied in mineral processing, with focus on the flotation process that may involve a number of chemicals for mineral separation.

2.1 Physical and chemical separation methods

2.1.1 Gravity separation

Gravity separation is the separation of minerals of different specific gravity by their relative movement in response to gravity and other forces such as centrifugal, magnetic and buoyant forces. As this separation process primarily is based on differences in the physical properties of the mineral(s) such as particle weight, size and shape, the particle size must be kept uniform. Gravity separation is the most original technique in mineral processing but is currently

being replaced by more recently introduced methods such as magnetic and flotation separation.

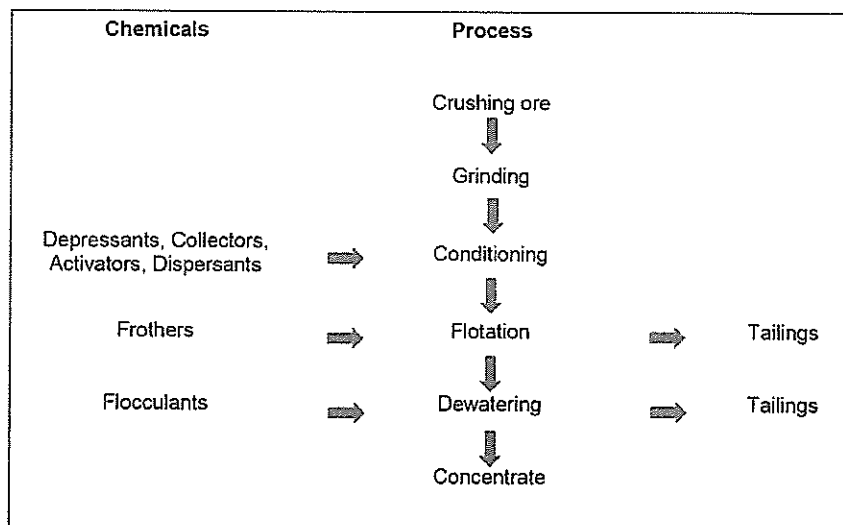
2.1.2 Magnetic separation

Magnetic separation is a process in which minerals are separated relative to differences in their magnetic properties. This separation method is most commonly used to separate natural magnetic iron ore (magnetite) from a variety of less-magnetic or non-magnetic rock material. Magnetic separation is generally a low-cost method of mineral recovery.

2.1.3 Flotation separation

Flotation is the most commonly used technique to recover/extract minerals from their ores. The method is based on the separation of particles from a mixture by altering the conditions of the particle surfaces, thereby inducing them to adhere to air bubbles. Flotation separation is based on the differences in the hydrophobicity of minerals. To separate minerals using flotation, fine air bubbles are introduced into a slurry of finely ground ore, mining chemicals and water. In the slurry, the chemically modified mineral particles collide with air bubbles, and minerals favouring contact with air will attach to the air bubbles and float to the surface. When the air bubbles accumulate at the surface, a froth forms and it eventually overflows. In contrast, more hydrophilic minerals remain in the slurry. Thus, there are two methods of flotation – direct flotation where the mineral attaches to the froth, overflows and can be collected, while the gangue remains in the slurry, and reverse flotation where the gangue attaches to the froth and the minerals remain in the slurry. To aid the flotation process, four different types of chemicals can be used: collectors, frothers, regulators and flocculants (see Figure 2).

Figure 2. Schematic illustration of mineral processing and use of mining chemicals for mineral separation.



2.1.4 Leaching

Leaching is a chemical process applied in the extraction of valuable metals such as copper, gold and uranium from ore via dissolution of metals in aqueous media. When applied in gold milling, the crushed ore is treated with a dilute alkaline cyanide solution to bring the gold into solution. Activated carbon is added whereupon the gold/cyanide complex adsorbs from

the solution onto the carbon. Because the carbon particles are much larger than the ore particles, the coarser carbon can then be separated from the slurry. After stripping, the process often involves electro-winding to retrieve the gold before melting it to a dore.

2.2 The use of chemicals for mineral separation

In terms of environmental protection and management in relation to the use of chemicals in the mineral separation processes, the discharge of liquid effluents and tailings disposal are subjects that require attention.

Mining generally generates relatively large volumes of waste called tailings. Tailings may contain hazardous minerals occurring in the original ore as well as inorganic and/or organic residuals from the mining chemicals used in the extraction processes. Thus, tailings often constitute a high potential pollution source; not only during the operation but also after mine closure. Also of concern is waste effluent in which residues of the chemicals used in the extraction processes may end. Often there is a need to discharge waste effluent to the environment and if needed the effluent will be treated prior to discharge to ensure that contaminant levels comply with regulatory established threshold values. Basic regulations have been set by the EU Directive (2008) to minimise the waste generated to the largest possible extent as well as to maximise recycling. Furthermore, safe disposal of industry-generated waste is included in the directive.

The type and quantity of each chemical reagent to be used have to be carefully selected in the early phase of a mining project since each individual mining chemical may impact the cost and the management of the waste generated during the entire lifetime of a mining project.

In the sections below, we provide some examples of mining chemicals employed in extraction processes, with focus on flotation.

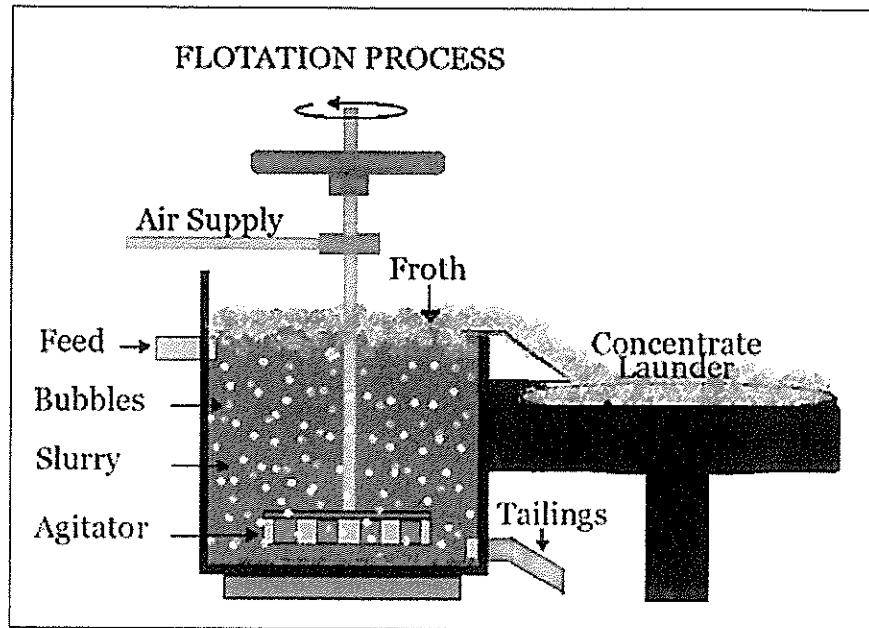
2.2.1 Flotation chemicals

Mining chemicals are the most important part of the flotation process. When planning the separation process, the selection of chemicals to obtain the most effective separation and concentration results is given high priority. Several hundreds of chemical products are available on the market. During the flotation process (Figure 3), four different types of mining chemicals may be required: collectors, frothers, regulators and flocculants.

Collectors

The basic purpose of a collector is to enhance the hydrophobicity of the selected minerals and thus promote attachment to the air bubbles. This is achieved by using a collector with a non-polar and maybe also a polar group. When the collector adsorbs on the mineral surface, the non-polar group is oriented towards the water phase and the polar part towards the mineral surface, making the mineral surface hydrophobic. When the air bubbles with the attached mineral particles accumulate at the surface, a froth is formed that can be skimmed off for either collection or rejection (Bulatovic, 2007).

Figure 3. Principle of flotation. Mining chemicals are added to the slurry to make the minerals attach to the air bubbles. A froth is formed, which can be skimmed off. (Illustration from: <http://www.miningeducation.com/2012/01/flotation-in-mining.html>).



Based on their ionic charges, collectors can be categorised into two groups:

- *Ionizing collectors*, which are compounds including both a non-polar and a polar group. An ionizing collector facilitates the dissociation of the minerals to ions in water. This type of collector can be either anionic or cationic.
- *Non-ionizing collectors*, which are non-polar compounds that have low solubility in water, for example hydrocarbon compounds (kerosene, transformer oil and synthetic hydrocarbon oils). This type of collector renders the mineral hydrophobic by 'covering' the mineral surface with a thin film.

Frothers

A frother is added in the flotation process to keep the froth stable. The frother concentrates at the interface of water and air bubbles and creates forces around the air bubble that prevent them from collapsing.

Frothers are heteropolar compounds containing a polar group (such as -OH, -COOH, -CO, -OSO₂ or -SO₂OH) and a hydrocarbon radical, capable of adsorbing in the water-air interface. There are two types of frothers, natural frothers such as pine oil and cresol, and synthetic frothers such as methyl isobutyl carbinol (MIBC). The volume of froth generated under standard operating conditions is often referred to as the froth power. The froth power is influenced by the type of collector and frother used. For example, froth power normally increases with the number of carbon atoms in the hydrocarbon radical up to 6 or 7 and then drops dramatically when the hydrocarbon chain has more than 8 carbon atoms. Mixing, for example, a longer chain xanthate (collector) with a short alcohol chain increases the volume of the froth (Bulatovic, 2007).

Regulators

A regulator controls the interaction of collectors between the individual minerals via different pathways. Regulators may, for example, react with specific mineral surfaces and thereby either pave (an activator type) or prevent (a depressant type) the adsorption of the collector to the mineral. Regulators may

also act by removing the collector coatings from specific mineral surfaces, thus causing depression of the selected mineral, or they may create a hydrophilic mineral surface that cannot react with collectors (Bulatovic, 2007).

The function of a regulator is related to changes in pH of the pulp and can be either an inorganic compound such as an acid, alkali and metal salt (e.g. sulphuric acid, lime, caustic soda, sodium cyanide, zinc-, copper sulphate etc.) or an organic compound such as a polymer-containing polar group such as -OH, -COOH, =CO, -NH₂, =NH and -SO₃H (e.g. starch, tannin, dextrin, cellulose gum, lignin sulphonates, gear gum etc.).

Flocculants

Flocculation is a process where fine suspended particles aggregate to form larger flocs. This enhances the separation of solids from the liquid phase. The flocculants are either inorganic compounds (such as calcium, aluminium or iron salts) for application where a cationic source is required or organic flocculants. The organic flocculants can be derived either naturally from, for instance, guar gums, hydrolysed starch and polysaccharides or be produced synthetically, such as acrylamide, polyacrylamides, polyacrylic salts etc. (Bulatovic, 2007).

3 Methods for environmental evaluation of chemicals

In the regulatory framework governing environmental risk assessment of chemicals, there is a general consensus that the evaluation should be based on the properties of the individual chemicals with regard to persistence (P), bioaccumulation potential (B) and toxicity (T).

3.1 Persistence

The persistence of a chemical describes the potential for the chemical to remain in the environment without degradation. Mechanisms by which compounds degrade include biodegradation and abiotic degradation.

Biological degradation refers to the chemical transformation mediated by organisms, particularly microorganisms such as bacteria and fungi. Chemicals that undergo ultimate biodegradation testing are usually analysed for 28 days in Organisation for Economic Co-operation and Development (OECD) tests. Depending on the results and the OECD test, chemicals are classified into one of three categories: readily biodegradable, inherently biodegradable or non-biodegradable. Readily biodegradable chemicals pass the most stringent biodegradability tests and criteria stipulating that the chemical must degrade e.g. >60% over the 28-day test (OECD 310, 2014). Inherently biodegradable chemicals are biodegradable but do not meet the readily biodegradable standards and must degrade between 20 to 60% during the 28-day analysis. Inherently biodegradable chemicals may take years to fully decompose and may require long-term remediation due to environmental persistence. Non-biodegradable chemicals do not have any characteristics of being biodegradable.

If no experimental data exist, models are often used to estimate degradation. Natural environmental conditions in which chemicals degrade differ from the conditions applied in the laboratory standard tests. Hence, extrapolation of the existing biodegradation information (either measured data from ready and inherent tests or results from Quantitative Structure-Activity Relationships (QSAR) modelling) to degradation rates in the environment may be difficult, and care should be taken when evaluating the results of the standard tests. This is especially important if data from these tests are used to evaluate the degradability at low temperature and in nutrient-poor environments, such as in the Arctic.

3.2 Bioaccumulation

Bioaccumulation occurs when a chemical accumulates in the tissues of an organism by all routes of exposure, for instance dietary and ambient environment sources. Bioaccumulation is the net result of processes of the uptake of the chemical into the organism through the respiratory surfaces and from the diet and elimination from the organism, the latter including respiratory exchange, fecal digestion and metabolic biotransformation of the parent compound and growth dilution. In environmental risk assessment, several metrics are used to predict the bioaccumulative potential of a chemical. The most common is the octanol-water coefficient (K_{ow}), the bioconcentration factor (BCF) and the bioaccumulation factor (BAF).

K_{ow} is a description of how a chemical will partition between octanol and water, high values of K_{ow} indicating a potential for the chemical to partition into the lipids of an organism and accumulate rather than partition into water and thus be more rapidly excreted. $\log K_{ow}$ is generally measured using the OECD standard shake flask test combined with High-performance liquid chromatography (HPLC). According to OSPAR guidelines (OSPAR, 2010), the bioaccumulative potential of a chemical can be classified into: $\log K_{ow} > 3$, which indicates a moderate potential for bioaccumulation, and $\log K_{ow}$ 4-7, which indicates a high potential for bioaccumulation.

The bioconcentration factor (BCF) describes the ratio of a concentration of a chemical in biota relative to the concentration of the chemical in the surrounding medium (water, sediment etc.). The bioconcentration is thus the process by which a chemical is absorbed by an organism from the ambient environment only through its respiratory and dermal surfaces. According to the OSPAR guidelines, the bioaccumulative potential of a chemical can be classified as having high ability for bioaccumulation when $BCF > 100$ (OSPAR, 2010).

3.3 Toxicity

The toxicity of chemicals is usually evaluated based on results of experimental studies for acute toxicity. Data on long-term chronic toxicity are not commonly available, but not less important. While acute toxicity effects generally are measured as behaviour or lethality, long-term effects often include mutagenic, carcinogenic and reproductive impacts.

Acute toxicity tests indicate the concentration of the chemical that causes 50% mortality (LC50) to the test organism during a specific period of time (24 to 96 h). LC50 is the most frequently applied test for assessing effects of chemical contaminants on aquatic organisms. Some acute toxicity studies are based on effects such as immobilisation, respiration or other identifiable endpoints, rather than lethal concentrations, and the effect is then given as EC50 (effect concentration). EC50 is the concentration of a chemical that causes effects in 50% of the organisms. When no laboratory data is available, the toxicological effects of the chemical are predicted from its structure and physical properties by using a quantitative structure-activity relationship (QSARs) model (ECHA, 2015).

A chemical is common classified as highly toxic when the acute LC50 toxicity is ≤ 1 mg/l or when long-term toxicity indicated as NOEC (no observed effect concentration) is ≤ 0.1 mg/L (ECHA, 2015).

Most often, toxicity testing is conducted under standard conditions at a temperature of 15 °C and with organisms living in tropic or temperate environments. This aspect needs to be taken into consideration when evaluating the toxicity of chemicals to be used in the arctic environment.

4 Environmental evaluation of selected mining chemicals

This chapter gives an environmental evaluation of selected chemicals that are widely used in the mining industry and potentially may be applied in mining in Greenland in the future. It is important to note that the below examples do not cover all chemicals used in the mining and milling processes worldwide. However, the underlying general principle of chemical assessment remains similar.

4.1 Xanthates

A widely used chemical group in the mining industry is xanthates. Xanthates are used in the flotation process as collectors in the separation of metal sulphides. About 300-500 g xanthates per ton ore are usually required for efficient separation (NICNAS, 2000; Australia, 1995).

Although a range of xanthates are available, in practice the low cost alkali metals are preferred. Some examples of alkali metal xanthates are sodium ethyl xanthate (SEX), sodium isopropyl xanthate (SIPX), sodium isobutyl xanthate (SIBX) and potassium amyl xanthate (PAX). Sodium xanthates have both a hydrocarbon chain and a polar group, and their selectivity to ore type decreases with increasing length of the hydrocarbon chain. Of the sodium xanthates, sodium ethyl xanthate has the shortest chain, which makes it highly selective to copper, nickel, lead, gold and zinc ores.

In the flotation process, the polar group of xanthate molecules attaches to the ore particles, with the non-polar hydrocarbon part sticking out, forming a hydrophobic film. When air is blown through the mixture, this film enables the mineral particles to be carried to the surface by the air bubbles (Lam, 1999). The float can then be collected and dried, either under ambient air conditions or at elevated temperatures in an oven. Most of the xanthate will stick to the concentrate, but trace amounts may follow the tailings and effluent.

The overall environmental concern for most xanthates is related to the degradation product carbon disulphide.

Due to the more or less similar behaviour of xanthates, we have chosen to focus on only one xanthate, namely sodium ethyl xanthate, in the environmental assessment in the following sections. Sodium ethyl xanthate is an organosulfur compound with the chemical formula $\text{CH}_3\text{CH}_2\text{OCS}_2\text{Na}$.

4.1.1 Persistence

The rate of degradation of sodium ethyl xanthate is dependent on several factors such as pH of the solution and temperature, ageing of the solution and presence of metal salts. For example, degradation is accelerated by the presence of metal salts, such as copper, iron, lead and zinc. Degradation of sodium ethyl xanthate occurs under acidic conditions, while it is stable in basic media when $\text{pH} \geq 9$ (Mustafa et al., 2004).

The abiotic degradation of xanthates can occur through three different pathways in aqueous solutions:

- 1) Dissociation into xanthic acid:

$$\text{C}_2\text{H}_5\text{OCS}_2\text{Na} + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OCS}_2\text{H} + \text{NaOH}$$

$$\text{C}_2\text{H}_5\text{OCS}_2\text{H} \rightarrow \text{CS}_2 + \text{C}_2\text{H}_5\text{OH}$$
- 2) Oxidation to dixanthogen:

$$2\text{C}_2\text{H}_5\text{OCS}_2^- + \text{H}_2\text{O} + 1/2\text{O}_2 \rightarrow (\text{C}_2\text{H}_5\text{OCS}_2)_2 + 2 \text{OH}^-$$
- 3) Hydrolytic decomposition:

$$6\text{C}_2\text{H}_5\text{OCS}_2^- + 3\text{H}_2\text{O} \rightarrow 6\text{C}_2\text{H}_5\text{OH} + \text{CO}_3^{2-} + 3\text{CS}_2 + 2\text{CS}_3^{2-}$$

While dissociation and oxidation reactions are minor and require acidic conditions, the hydrolytic reaction proceeds at neutral or alkaline pH. This reaction is self-accelerating as it is catalysed by the alcohol formed as a product. Its rate increases with increasing concentrations of the chemical and with temperature. Decomposition is also accelerated by the presence of metals, such as copper, iron, lead or zinc, which act as catalysts.

Xanthates degrade rather quickly and results of residue analyses have generally shown half-lives ($T_{1/2}$) of xanthates in water of 2 to 8 days depending on the length of the alkyl chain (Table 1). The degradation time of xanthates in cold climates is however unknown.

4.1.2 Bioaccumulation

Xanthates have been shown to bioaccumulate in organisms (Xu et al., 1988). For example, the disappearance of xanthate from water (conc. 0.025 µg/ml) has been found to be enhanced by addition of the aquatic plant duck weed (*Lemna minor*), which accumulates xanthates, and bioaccumulation factors (BCF) as high as 1000 have been reported for plant material (Xu et al., 1988). Xanthates have also been found to enhance the bioaccumulation of heavy metals (Boening, 1998) as they may form hydrophobic complexes with di- or trivalent heavy metals such as Zn, Cd, Pb and Cu. Those complexes facilitate uptake through organism cellular membranes and, by way of example, a ten-fold increase of Cd in trout gill tissue has been observed at xanthate levels as low as ~ 0.2 µg/l (Block & Pärt, 1986).

4.1.3 Toxicity

Xanthates are used in substantial quantities in the mining industry. Xanthates are highly toxic to aquatic algae at concentrations of < 1 mg/l (Table 1). Bertillas et al. (1985) studied the potential environmental effects of xanthates with and without presence of metals. Their study showed that the xanthates were highly toxic to algae and bacteria (EC50: 0.025 - 0.65 mg/l) but less toxic to fish (LC50: 11 - 65 mg/l). When xanthates were tested in the presence of metals, a great increase in metal toxicity was observed, up to 25 times for algae and 3.5 times for fish. This was consistent with the finding of higher accumulation of metals in fish tissues.

As xanthates are hydrolysed by stomach acid, the main hazard from exposure to xanthates is considered to arise from the degradation products, such as alcohol and carbon disulphide (CS₂). Carbon disulphide has been found to exhibit low to moderately acute toxicity in organisms and has been associated with a number of long-term effects, including neurological and reproductive effects (MSDS Carbon Disulfide, 1999). Both sodium ethyl xanthate and CS₂ are included in the NOHSC List of Designated Hazardous Substances.

NOHSC stands for National Occupational Health and Safety Commission (Australia).

Sodium ethyl xanthate is classified as a 'Priority Existing Chemical' in Australia (NICNAS 2000), meaning that its manufacture, handling, storage, use or disposal may result in adverse health or environment effects. This decision was justified by the widespread use of the chemical in industry and its decomposition to the toxic and flammable carbon disulphide gas.

Table 1. Data on toxicity, degradation and bioaccumulation of xanthates.

Reagent	Organism	Effect conc.	Reference
Na-ethyl xanthate	Invertebrate (<i>Daphnia magna</i>)	0.35 mg/l	EC50 MSDS Sodium-ethyl xanthate, 2015
	Invertebrate (<i>Daphnia magna</i>)	0.35 mg/l	EC50 Xu et al., 1988
	Fish (<i>Oncorhynchus mykiss</i>)	13 mg/l	LC50 MSDS Sodium-ethyl xanthate, 2015
	Algae (<i>Lemna minor</i>)	< 10 mg/l	EC50 Xu et al., 1988
	Bioaccumulation	Log K _{OW} < 0	MSDS Sodium-ethyl xanthate, 2015
	Degradation	>60% in 8 days	MSDS Sodium-ethyl xanthate, 2015
	Degradation	T _{1/2} : 4.1 days	Boening, 1998
Na-isopropyl xanthate	Invertebrate (<i>Daphnia magna</i>)	0.33 mg/l	EC50 Xu et al., 1988
	Degradation	T _{1/2} : 3.5 days	Xu et al., 1988
	Algae (<i>Pseudokirchneriella subcapitata</i>)	ca. 0.5 mg/l	EC50 Vigneault et al., 2012
Na-isobutyl xanthate	Invertebrate (<i>Ceriodaphnia dubia</i>)	ca. 3 mg/l	EC50 Vigneault et al., 2012
	Invertebrate (<i>Daphnia magna</i>)	3.6 mg/l	EC50 Xu et al., 1988
Na-isopentyl xanthate	Algae (<i>Lemna minor</i>)	< 10 mg/l	EC50 Xu et al., 1988
	Degradation	T _{1/2} : 3.0 days	Xu et al., 1988
K-amyl xanthate	Algae (<i>Pseudokirchneriella subcapitata</i>)	ca. 0.5 mg/l	EC50 Vigneault et al., 2012
K-amyl xanthate	Invertebrate (<i>Daphnia magna</i>)	3.67 mg/l	EC50 MSDS Potassium amyl xanthate, 2015
	Invertebrate (<i>Ceriodaphnia dubia</i>)	ca. 3 mg/l	EC50 Vigneault et al., 2012
	Fish (<i>Danio rerio</i>)	>10-100 mg/l	LC50 MSDS Potassium amyl xanthate, 2015
	Bioaccumulation	Log K _{OW} -0.76	MSDS Potassium amyl xanthate, 2015
K-pentyl xanthate	Invertebrate (<i>Daphnia magna</i>)	3.0 mg/l	EC50 Xu et al., 1988
	Degradation	T _{1/2} : 2.5 days	Xu et al., 1988

4.1.4 Summary

Trace concentrations of xanthates are likely to be found in the tailings slurry and in the effluent. Despite that xanthates may be degraded by hydrolysis in tailings dams, it is important that tailings waste streams are not discharged to waterways as they are toxic to the aquatic fauna. Furthermore, the degradation product of xanthate, carbon disulphide, is toxic.

The effects and fate of xanthate in the arctic environment have not yet been the subject of study. Laboratory studies conducted under temperate conditions show that xanthates decompose gradually under alkaline and neutral conditions and instantly under acidic conditions. Xanthates residues were, however, still found in the environment for a certain period. Standard test results indicated that xanthates and their degradation products are toxic to aquatic invertebrates and less toxic to fish species and that they may bioaccumulate. Xanthates increase the toxicity and bioaccumulation of metals.

4.2 Magnafloc (PAM)

Magnafloc is used as a mining chemical in leaching, flocculation and clarification. Magnafloc products include a wide variety of forms such as solid grades in bead and gel form, liquid dispersion and liquid inverse emulsion.

Magnafloc products are formed from acrylamide subunits and consist of anionic or cationic polyacrylamide polymers (PAM). While cationic polymers, such as Magnafloc 368, are used mainly as coagulants, anionic polymers, such as Magnafloc 156 and Magnafloc 338, are used as flocculants and bind together suspended particles into higher molecular weight aggregates that more readily settle out of the solution.

4.2.1 Persistence

Polyacrylamide has been reviewed by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) in Australia, and according to NICNAS (2002) – despite some biotic and abiotic degradation – polyacrylamide is unlikely to degrade to the more environmentally problematic acrylamide in the environment. Similarly, the Material Safety Data Sheets (MSDS) for Magnafloc 338 and 156 evaluate that these products are not readily biodegradable (Material Safety Data Sheets, MSDS) according to OECD criteria.

4.2.2 Bioaccumulation

No information is given in the MSDS for Magnafloc 338, 368 or 156. Based on its structural properties, the polymer is evaluated not to be biologically available, wherefore bioaccumulation in organisms is not to be expected.

4.2.3 Toxicity

Polyacrylamide itself is relatively non-toxic (Table 2). However, it is known that commercially available polyacrylamide contains residual amounts of the more toxic acrylamide (AMD) remaining from its production. AMD is reported to be neurotoxic to humans and is classified by WHO and EU as a carcinogenic (level 2), mutagenic (level 2) and reprotoxic (level 3) compound (Guezennec et al., 2015).

Table 2. Data on toxicity and degradation of Magnafloc.

Reagent		Effect conc.		Reference
Magnafloc 338	Fish (<i>Oncorhynchus mykiss</i>)*	>100 mg/l	LC50	MSDS Magnafloc 338, 2013
	Invertebrate (<i>Daphnia magna</i>)*	> 100 mg/l	LC50	MSDS Magnafloc 338, 2013
Magnafloc 10	Fish (<i>Pimephales promelas</i>)	141 mg/l	EC50	Vigneault, 2012
	Fish (<i>Oncorhynchus mykiss</i>)	58 mg/l	LC50	Vigneault, 2012
	Invertebrate (<i>Daphnia magna</i>)	> 903 mg/l	LC50	Vigneault, 2012
Magnafloc 156	Fish (<i>Salvenius namaycrush</i>)	>600 mg/l	LC50	Liber et al., 2005
	Fish (<i>Oncorhynchus mykiss</i>)*	>100 mg/l	LC50	MSDS Magnafloc 156, 2014
	Invertebrate (<i>Daphnia magna</i>)*	> 100 mg/l	LC50	MSDS Magnafloc 156, 2014
Magnafloc 368	Fish (<i>Salvenius namaycrush</i>)	2.08 mg/l	LC50	Liber et al., 2005
	Invertebrate (<i>Ceriodaphnia dubia</i>)*	>10 mg/l	LC50	MSDS Magnafloc 368, 2012
	Degradation	<10% in 28 days		MSDS Magnafloc 368, 2012

* By analogy with a similar composition.

The toxicity of polymers to aquatic organisms is found to depend on their chemical structure and physical properties. Cationic polymers with quaternary amines are toxic to aquatic organisms in low concentrations (<1 mg/L). Although the toxicity of cationic polymers to fish increases with increasing charge density, the toxicity to planktonic invertebrates has been found to relate to the molecular weight of the polymer. In general, anionic polymers tend to be less toxic to fish than cationic polymers, and a 96-h LC50 of >20 mg/L has been estimated for fathead minnows (*Pimephales promelas*) (de Rosemond & Liber, 2004 – and references herein).

4.2.4 Summary

Based on its structural properties the polymer is not readily biologically available and bioaccumulation in organisms is not to be expected. No information on toxicity or fate of the chemicals exists for arctic areas. The potential environmental hazard does not necessarily concern the PAM itself, at least not the anionic PAMs which mostly are considered non-toxic. However the degradation products of PAM and the residual AMD contained in the flocculants due to an incomplete polymerization process have shown high toxicity. Residual AMD in products of PAM should have high concern.

4.3 Flotigam EDA

Flotigam EDA is used in the mining industry in the flotation process, which is based on differences of surface characteristics among the minerals present in the pulp. Flotigam EDA is mostly used for separation of hematite (Fe_2O_3) and quartz (SiO_2). Both hematite and quartz particles are avid for water in their natural condition. During flotation, the hematite particles are rendered even more hydrophilic by the action of starch, while those of quartz become hydrophobic by the action of amine. Amine also plays a role in stabilising the froth generated by the addition of air to the system and facilitates the kinetics of quartz particles-air bubbles interaction. Hydrophobic particles (i.e. the quartz) are air avid and are carried by the froth phase, while hydrophilic (hematite) particles remain in contact with water, allowing selective separation between the quartz and hematite.

4.3.1 Persistence

Biodegradability assays have shown that Flotigam EDA is biodegradable at concentrations assayed in industrial effluents. The biodegradation is estimated to >95% in 28 days (Peres, 2000; Araujo et al., 2010), but less as concentrate (20% in 28 days).

4.3.2 Bioaccumulation

No data are available on bioaccumulation or bioconcentration factors. Flotigam EDA may form complexes with heavy metals, thus increasing their uptake, implying that fish may accumulate heavy metals more readily.

4.3.3 Toxicity

Flotigam EDA reagent is considered toxic to aquatic organisms and may cause long-term adverse effects in the aquatic environment (Table 3).

Table 3. Data on toxicity and degradation of *Flotigam EDA*.

Reagent		Effect conc.		Reference
Flotigam EDA	Invertebrate (<i>Daphnia magna</i>)	6.8 mg/l	LC50	Garcia et al., 2007
	Invertebrate (<i>Daphnia magna</i>)	0.79 mg/l	EC50	Peres et al., 2000
	Biodegradability (concentrate)	20% in 28 days		Peres et al., 2000
	Biodegradability (effluent 7%)	>95% in 28 days		Peres et al., 2000

4.3.4 Summary

Flotigam EDA as concentrate is considered not readily biodegradable and it is toxic to aquatic organisms and may further form complexes with heavy metals, increasing their uptake, i.e. aquatic organisms may accumulate heavy metals more readily. No data on the fate of Flotigam EDA are available for arctic environments, however.

As Flotigam EDA is considered highly toxic to aquatic organisms and may persist at low temperatures in the cold Arctic, it may have long-term adverse effects on the aquatic environment.

4.4 Ferrosilicon

Ferrosilicon is used in the mining industry in the dense medium separation (flotation) of, for instance, the iron ore. A dense medium suspension consisting of water and ferrosilicon is used in most high density mineral separation processes.

Ferrosilicon is a blend consisting of mostly iron, silicon, titanium and aluminum. As an example, Ferrosilicon may contain 70-80% iron, 10-20% silicon, 5-10% titanium, 1-5 % aluminum and < 1% trace elements (chromium (Cr), magnesium (Mg), manganese (Mn), vanadium (Va), nickel (Ni), copper (Cu), zirconium (Zr) and molybdenum (Mo)). Variations in the manufacturing process of a reagent may result in a change in the hazardous impurities in the chemical. Those impurities are of environmental concern due to their toxicity, persistence and bio-accumulative properties. The acidic tailings conditions encountered in some tailings dams may enhance the mobility of those metals. Ferrosilicon is a grey solid-granular that is insoluble in water, and mixed with mineral acids it may generate flammable and explosive hydrogen gas. Due to its high density (6.7 g/cm³), Ferrosilicon settles fast to the bottom of the tailings dam and is buried in the sediment.

4.4.1 Persistence

The product is insoluble in water. The iron, as ferro-iron (FeII), can be oxidised to ferri-iron (FeIII), a process that will partly lead to dissolution of the product and release of contaminants (product impurities) to the water body. However, this process is oxygen demanding, and the low oxygen concentration in the water (if aqueous deposition of tailings is selected) and the low diffusion rate compared with air will limit the oxidation of the product to negligible rates. Thus, in anoxic waters, ferrous iron is mobilised from sediments and diffuses into the water column. Aluminum oxide is not mobile in the environment unless the pH of the aqueous environment is below 5.5 or above 8.5.

When discharged to seawater, suspended iron oxyhydroxides are rapidly precipitated and the vast majority of the iron present occurs in particulate form and will effectively be removed from the solution.

4.4.2 Bioaccumulation

Some elements of the Ferrosilicon are known to bioaccumulate. Fe, which represents the primary component, is known to bioaccumulate to a high degree. As the product as such is a blend of elements and its composition varies, each product should be treated individually.

4.4.3 Toxicity

As Ferrosilicon is a blend of elements and the specific toxicity will depend on the exact composition of the product, each product should be treated individually.

4.4.4 Summary

The environmental fate of Ferrosilicon is most likely determined by pH and salinity. Lower pH can lead to release of the cations, whereas an increase in pH can lead to release of the anions. It is recommended that the guideline values for Mo, Mn, Cr, Cu, Ni, Va and Zr released from the application of Ferrosilicon to the environment should not be exceeded (Table 4).

Table 4. Guideline values in freshwater for heavy metals and trace elements found as impurities in Ferrosilicon.

Element	Guideline value (µg/l)	Reference
Cu	2	MRA 2015. EIA Guidelines
Hg	0.05	MRA 2015. EIA Guidelines
Pb	1	MRA 2015. EIA Guidelines
Fe	300	MRA 2015. EIA Guidelines
Va	4.1	Guidelines from Danish legislation (BEK, 2010)
Zr	4	Guidelines from Canadian Legislation - Provincial water quality objectives of the Ministry of Environment and Energy. Ontario. February 2009
Cr (III)	3	MRA 2015. EIA Guidelines
Ni	5	MRA 2015. EIA Guidelines
Mo	67	Guidelines from Danish legislation (BEK, 2010)
Mn	1200	Guidelines from Australia/New Zealand (2000)

4.5 Methyl Isobutyl Carbinol (MIBC)

Methyl isobutyl carbinol (MIBC) is used as a frother in mineral flotation in order to reduce the bubble size and increase the stability of the froth in the flotation process. MIBC is an organic chemical compound and is a liquid derivative of acetone with a pungent alcohol odour. It has limited solubility in water but is miscible with most organic solvents.

The environmental distribution of MIBC depends on factors such as climatic conditions (light intensity, energy and duration, temperature, wind and humidity), soil/sediment characteristics and geographical location.

4.5.1 Persistence

In many applications, MIBC is used in closed systems. Environmental releases are considered unlikely and would only result from accidents.

In the environment, fast photodegradation and biodegradation of MIBC will limit the potential exposure of biota. MIBC does not have hydrolysable groups and hydrolysis is therefore not a degradation pathway. MIBC is predicted to be photodegraded by reaction with hydroxyl radicals in the atmosphere with an estimated half-life of approximately 10 hours (US EPA, 2000c). Biodegradation assay studies have shown that MIBC is readily biodegradable with 94% biodegradation after 20 days (Price et al., 1974). Based on the above and on available data, MIBC is regarded to have low persistence (US EPA, 2008).

As MIBC is moderately volatile and slightly soluble in water, it will, when introduced to water, remain in the water. It has low potential to bind to soil or sediment.

4.5.2 Bioaccumulation

A low bioaccumulation potential of MIBC is expected based on the partition coefficient (log K_{ow}) of 1.68 and other physical/chemical parameters (US EPA, 2008).

4.5.3 Toxicity

Based on the available data, MIBC exhibits low toxicity to aquatic organisms (Table 5).

Table 5. Data on toxicity and degradation of MIBC.

Reagent	Effect conc.	Reference
MIBC Algae (<i>Pseudokirchneriella subcapitata</i>)	334 mg/l	EC50 OECD SIDS, 2005 and references herein
Invertebrate (<i>Daphnia magna</i>)	337 mg/l	EC50 OECD SIDS, 2005 and references herein
Fish (<i>Oncorhynchus mykiss</i>)	359 mg/l	LC50 OECD SIDS, 2005 and references herein
Biodegradability (concentrate)	94% in 20 days	Price et al., 1974.
Bioaccumulation	Log K_{ow} 1.68	OECD SIDS, 2005 and references herein

4.5.4 Summary

MIBC is an alcohol and is readily biodegraded, which suggests that the chemical will be rapidly and completely removed from water and soil environments, including biological wastewater treatment plants. Consequently, MIBC is unlikely to persist in the environment.

MIBC has low bioaccumulation potential and little toxicity. The fate characteristics and low toxicity of this chemical combined indicate that MIBC poses a low environmental risk.

No data are available on arctic conditions and it is possible that degradation will be slower at colder temperatures.

5 Regulatory framework governing environmental assessment of mining chemicals

This chapter gives an overview of the regulatory framework governing the environmental assessment of mining chemicals applied in Greenland, EU, OSPAR, Australia, Canada and the United States.

5.1 European Union regulatory framework

In 2007, the European Union (EU) established the integrated registration/regulation system REACH (Registration, Evaluation, Authorisation and restriction of CHemicals) for the management of chemicals (EU (EF) No 1907/2006 (<http://echa.europa.eu/web/guest/regulations/reach/>)).

The European Chemicals Agency (ECHA) is the agency managing REACH, which involves:

- **Registration:** Companies have the responsibility of collecting information on the properties and the uses of substances that they manufacture or import at or above one ton per year. They also have to make an assessment of the hazards and potential risks presented by the substance.
- **Evaluation:** ECHA and the Member States evaluate the information submitted by the companies. The quality of the registration dossiers and the testing proposals are examined and it is clarified whether a given substance constitutes a risk to human health or the environment.
- **Authorisation:** The authorisation procedure aims to assure that the risks of substances of very high concern are properly controlled and that these substances are progressively sought replaced by alternatives while ensuring the good functioning of the EU internal market.
- **Restriction:** A restriction can be placed to protect human health and the environment from unacceptable risks posed by chemicals. A restriction may result in a limit or ban of production, introduction to the market or the use of a substance.

REACH requires that the industries that manufacture and import the chemicals must assess the environmental risks and provide appropriate safety information to their users. According to the REACH regulation, a chemical safety assessment (CSA) has to be performed for chemicals manufactured and imported in quantities starting at ten tons per year. The chemical safety assessment of a reagent comprises the following steps: (1) assessment of the human health hazard, (2) assessment of physico-chemical properties, (3) assessment of the environmental hazard and (4) assessment of whether the substance is considered PBT (persistent, bio-accumulative and toxic) and/or vPvB (very persistent and very bioaccumulative). For more information concerning chemical regulations, guidance, classification, labelling and testing proposals in REACH, please see: www.echa.europa.eu/regulations.

In sum, the main features of REACH are that manufacturers and importers of chemicals must register substances with the EU Chemicals Agency. This also applies to substances imported and/or produced as part of a mixture and in some cases also substances in articles. Along with the registration, information on the environmental health effects and the risks of using the product must be provided. When information on a product is limited, the

authorities assess proposals for new trials. The submitted data are assessed, and it is evaluated whether more knowledge is required in order to decide whether the use of the substances should be regulated.

Comment: Even though Greenland is a member of the Kingdom of Denmark, which is a member of EU, Greenland is self-governed and not an EU member, implying that the EU REACH regulation does not automatically apply to Greenland.

5.2 OSPAR Commission regulatory framework

OSPAR, the Convention for the Protection of the Marine Environment of the North East Atlantic, has developed a list of potential problematic chemicals, the List of Substances of Possible Concern. The list includes certain hazardous substances on the basis of their intrinsic hazardous properties of persistence, ability to bioaccumulate and toxicity and is regularly revised as new information becomes available. In order to prioritise the substances of highest concern for immediate action, OSPAR has selected the substances from the list according to their actual occurrence and effects in the marine environment. This selection procedure has ended up in the OSPAR List of Chemicals for Priority Action or the OSPAR Priority list, which includes 42 substances or groups of substances. Furthermore, OSPAR has listed over 300 substances of possible concern (OSPAR, 2011). In the work on substances of possible concern, OSPAR is relying on progress on the evaluation of substances under the REACH regulation and on the prioritisation of substances under the EU Water Framework Directive for integrated river basin management for Europe. Within the regulation of use and discharge of chemicals as a result of offshore activities, OSPAR has protocols for pre-screening of chemicals. The purpose of this pre-screening is to allow authorities to identify substances intended to be used or already in use in offshore activities with the aims of a) substituting, and ultimately phasing out, those substances which are hazardous and b) regulating and controlling the substances where necessary. The pre-screening of chemicals is based on lists of OSPAR and EU, as well as the intrinsic hazardous properties of persistence, ability to bioaccumulate and toxicity.

Within OSPAR, the principles of Best Available Techniques (BAT) and Best Environmental Practice (BEP) are required. This also includes, when appropriate, clean technology, in the effort to prevent and eliminate marine pollution (<http://www.ospar.org/about/principles/bat-bep>). BAT is by OSPAR (in appendix 1 of the OSPAR Convention) defined to 'the latest stage of development (state of the art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions and waste'. BEP is defined as 'the application of the most appropriate combination of environmental control measures and strategies'. Thus, it follows that BAT and BEP for a particular source will change with time due to technological advances, economic and social factors, as well as changes in the scientific knowledge and understanding.

5.3 Australian regulatory framework

The Australian Government assesses industrial chemicals under the Industrial Chemicals (Notification and Assessment) Act 1989 and the Industrial Chemicals (Notification and Assessment) Regulations 1990.

Australia's Chemicals Agency, the National Industrial Chemicals Notification and Assessment Scheme (NICNAS), is administered by the Australian Government, Department of Health (<http://www.nicnas.gov.au/>). NICNAS performs two types of chemicals assessments: the Non-Priority Existing Chemical (non-PEC) and the Priority Existing Chemical (PEC).

NICNAS applies internationally accepted methodologies to assess existing or new chemicals:

- Risk assessment of chemicals.
- Human health hazard assessment.
- Occupational health and safety assessment.
- Public health assessment.
- Environmental assessment.

It is the Department of the Environment, Water, Heritage and the Arts (DEWHA) that undertakes the environmental risk assessments of industrial chemicals for NICNAS.

The steps taken to carry out the risk assessment are presented in the Chemical Risk Assessment Guidance Manual (available at the Environment Protection and Heritage Council webpage: www.scew.gov.au/resource/chemical-risk-assessment-guidance-manuals). This guidance provides the framework for conducting environmental risk assessments of chemicals and includes:

- Data requirements. Relevant environmental physico-chemical data, other environmental fate test data and required information on environmental impact.
- Data evaluation. Evaluation of the data for its reliability, relevance and adequacy.
- Environmental exposure. Assessment of the potential exposure to the environment during all stages of the chemical's life cycle.
- Environmental effects assessment. Assessment of the effects of the chemicals on the environment.
- Assessment of the persistence, bioaccumulation and toxicity of the chemical.
- Risk characterisation and risk management. A concluding assessment of the potential and the magnitude of the risk to the environment and recommendations about environmental risk management actions.

5.4 Canadian regulatory framework

Environmental risk assessment of chemicals in Canada is conducted by Environment Canada and Health Canada according to the Ecological Assessment of Substances under the Canadian Environmental Protection Act (CEPA, 1999). The assessments conducted for new and existing substances follow the weight-of-evidence approach and precautionary principle. The weight-of-evidence approach involves the use of several component lines of evidence to make decisions in all phases of an assessment, including risk characterisation. These lines of evidence can include risk quotients, results of probabilistic analyses, evidence of harm in the field, evidence of persistence and potential for bioaccumulation, and high or increasing levels of exposure.

Environmental assessment under CEPA (1999) includes several components:

- Characterisation of environmental entry, fate and exposure. Information is gathered on the ways in which a substance enters and behaves in the environment and on how non-human organisms can be exposed to the substance and the effects of exposure. This characterisation also includes persistence and bioaccumulation.
- Characterisation of ecological effects. The potential for the substance to cause adverse ecological effects is evaluated.
- Risk characterisation. The potential for ecological risk of a substance is determined using multiple lines of evidence gathered during the assessment.

A more detailed overview of environmental risk assessments of chemicals in Canada can be found at Environment Canada (http://www.ec.gc.ca/lcpe-epa/documents/substances/eas_over-view-eng.pdf).

5.5 United States regulatory framework

In the United States, the Environmental Protection Agency (US EPA) performs chemical risk assessment based on the Toxic Substances Control Act of 1976 (TSCA) and regulates the introduction of new and already existing chemicals (<http://www.epw.senate.gov/tsca.pdf>).

The US EPA objectives regarding chemical risk assessment are:

- To assess and regulate new commercial chemicals before their entrance into the market.
- To regulate chemicals that pose an “unreasonable risk to health or to the environment”.
- To regulate the distribution and use of these chemicals.

Chemicals that are listed on the TSCA Inventory are referred to as existing chemicals, while chemicals not listed are referred as new chemicals. Generally, manufacturers must submit pre-manufacturing notification to the EPA prior to manufacturing (or importing) new chemicals not listed in the 1976 act by using a Pre-Manufacturing Notice (PMN). The PMN submissions require all available data on chemical identity, production volume, by-products, use, environmental release, disposal practices and human exposures. Manufacturers need also to generate and report to EPA data on risk, manufacturing and processing, adverse health effects, health and safety studies and substantial risks. New chemical notifications are reviewed by the EPA. If the EPA finds an unreasonable risk to human health or the environment, it may regulate the substance in a variety of ways, from limiting uses or production volume to outright banning them.

The EPA may issue a TSCA Order to prohibit or limit activities associated with the chemical if the EPA determines that:

- There is “insufficient information” to evaluate the human health and environmental effects of the substance.
- The substance may present an unreasonable risk of injury to human health or the environment (the ‘risk-based’ finding).
- The substance will be produced in substantial quantities and may be anticipated to enter the environment in substantial quantities, or there may be significant or substantial human exposure (the “exposure-based” finding).

5.6 Greenlandic regulatory framework

The Mineral Resource Authority under the Greenland Government comprises the Mineral License and Safety Authority (MLSA) and the Environment Agency for the Mineral Resources Activities (EAMRA). The MLSA is the overall administrative authority for licenses and mineral resources activities, and it is the authority for safety matters including supervision and inspection.

EAMRA is the administrative authority for environmental matters relating to mineral resources activities and is the authority for protection of the environment and nature, environmental liability and environmental impact assessments. At present in Greenland, all mining chemicals and use of chemicals in the processing of minerals have to be approved by EAMRA.

The Greenlandic regulatory framework governing minerals resources activities comprises:

- Greenland Parliament Act no. 7 of 7 December 2009 on mineral resources and mineral resources activities (the Mineral Resources Act which came into force on 1 January 2010) with subsequent amendments – Greenland Parliament Act no. 26 of 18 December 2012, effective as from 1 January 2013, and Greenland Parliament Act no. 6 of 8 June 2014, effective as from 1 July 2014,
<http://www.govmin.gl/index.php/about-bmp/legal-foundation>.
- Rules for fieldwork and reporting in Greenland.
<http://www.govmin.gl/minerals/terms-rules-laws-guidelines>.
- EIA Guideline.
https://www.govmin.gl/images/stories/minerals/Guidelines_for_preparing_an_Environmental_Impact_Assessment_EIA_report_for_mineral_exploitation_in.pdf.

Up to date, Greenland has developed a strategy for use and discharge of drilling mud including chemicals in the offshore industry (DCE, 2014).

Comment: In Denmark, a Product Registry (PROBAS) was established under the Working Environment Authority and the Environmental Protection Agency in 1979. The objective of the registry is to provide an overview of the spread and use of hazardous substances and materials in Denmark, and at present the registry contains information on approx. 38,000 registered products. A product must be registered if it is manufactured or imported in quantities equal to 100 kg per year used for commercial purposes. PROBAS includes information about substances and materials, such as trade name, composition, danger labels, quantity manufactured/imported as well as use (for instance in paint), and in which trades or industries the substances or materials are used (<http://engelsk.arbejdstilsynet.dk/en/produktregistret>).

6 Recommendations for environmental risk assessment in Greenland

The environmental risk assessment framework reviewed in this paper is based on an evaluation of the properties of the individual chemicals with focus on persistence, bioaccumulation and toxicity (PBT). Such a framework is used in the assessment methodology of EU, Australia, Canada and US, and it is recommended that environmental risk assessment of mining chemicals to be used in Greenland follows the same principles. With respect to mining chemicals of particular concern to the marine environment, the list developed by the Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR) should be taken into consideration as well.

At present, all mining chemicals and use of chemicals in the processing of minerals must be approved by the Greenlandic authorities. It is recommended that this procedure continues. Consequently, the mining companies have to submit an application in good time before the intended use of the chemical and the application must include a full description of the chemicals to be applied in the mining project, including detailed information on the composition of the products with CAS numbers. Data on toxicity, biodegradability and potential for bioaccumulation have to be provided and if such information does not exist, data on product ingredients must be made available.

The application must also contain information on the proposed quantities of the chemical to be used and details on its chemical and physical properties and fate, including how the chemical will be managed and handled after its use and its concentrations and quantities in tailings, process water and drainage water.

The risk assessment undertaken by the authorities involves a pre-screening of chemicals based on information in PROBAS, OSPAR and EU lists in order to gather information on chemical and physical properties, the chemical forms and quantities of the proposed chemicals as well as on persistence, bioaccumulation potential and toxicity. In case of uncertainty, supplementary studies/tests must be conducted.

It is highly important to take into consideration that the degradation of chemicals may be slower under arctic conditions than at temperate conditions under which most chemicals have been tested and that bioaccumulation might be higher. Very little information on toxicity, degradation and bioavailability in arctic conditions is generally available. Therefore, in case of uncertainty, tests should be performed under arctic conditions (e.g. low temperatures) and toxicity tests should be performed with arctic organisms. Chemicals that are persistent and have the potential to bioaccumulate or are persistent and toxic should be categorised as chemicals of high concern, and substitution of such chemicals with less harmful substances should be sought.

In the active phase of the mining, an environmental programme must be implemented by the mining company to self-monitor the use of chemicals and release to the environment (as described in MRA, EIA Guidelines, 2015). Effluents of mineral processing as well as drainage and seepage effluents must comply with the requirements specified by the environmental regulatory authorities. The requirements should contain discharge limits both as

concentrations and total amounts within a specified timeframe. As part of a compliance programme, such self-monitoring must be inspected and verified regularly by the environmental regulatory authorities.

Overall, it is recommended that all activities involving use of chemical agents in mineral extraction should comply with the best available techniques (BAT) and best environmental practice (BET).

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REVIEW ON ENVIRONMENTAL RISK ASSESSMENT OF MINING CHEMICALS USED FOR MINERAL SEPARATION IN THE MINERAL RESOURCES INDUSTRY AND RECOMMENDATIONS FOR GREENLAND

This report provides background knowledge that allows carrying out an environmental risk assessment of mining chemicals that expectedly will be used for separation of minerals in the future in the mining resource industry in Greenland. The Greenlandic environment is as other arctic areas particularly sensitive to contaminants. Therefore, the standard tests on mining chemicals performed under temperate conditions may require some adjustment, such as use of additional sensitivity factors, when applied for environmental assessments under arctic conditions.

The general separation processes of minerals and the application of different types of chemicals are described. Further, the present review provides an environmental evaluation of selected mining chemicals that potentially may be applied in mineral separation processes in Greenland in the future. This is followed by a description of the regulatory framework for environmental risk assessment of chemicals in other relevant countries.

