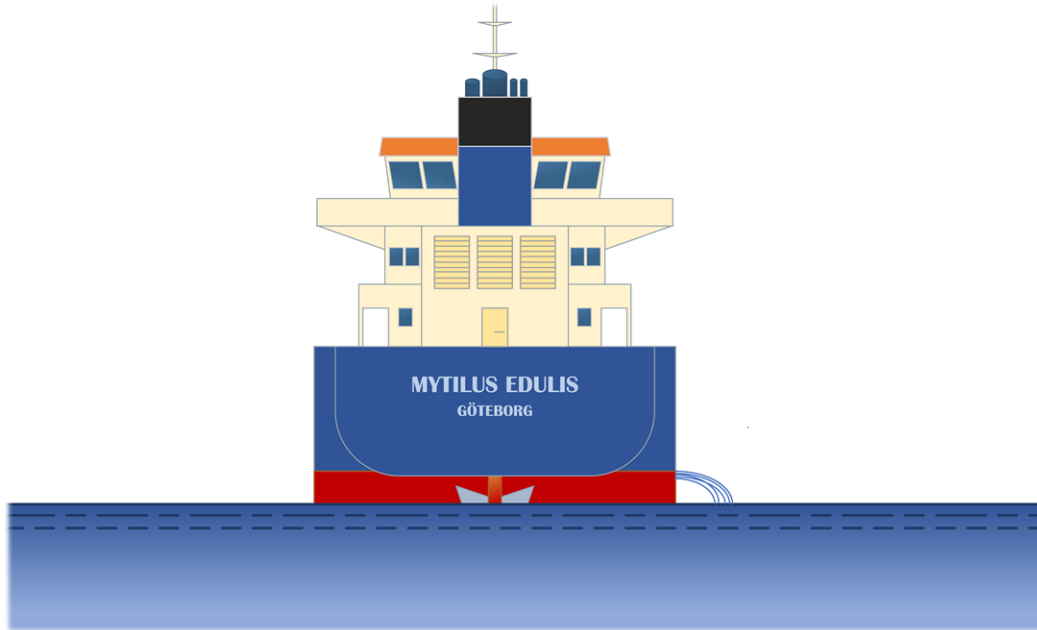




CHALMERS



Copper load to the marine environment from Impressed Current Anti-Fouling (ICAF) systems

Bachelor thesis for Marine Engineering Program

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:

Figure displaying a merchant vessel, with the sea cooling water discharge visible on the starboard side (p. 5).

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PREFACE

This thesis was made as a part of the authors' path to the marine engineering examination at the Chalmers University of Technology. We wish to give the biggest appreciation to our supervisor, Professor Ida-Maja Hassellöv, who with her great knowledge and professionalism guided us through the work with this thesis. We are grateful beyond words.

We would also like to give a special thanks to all the crews and personnel onboard the vessels and shipowner offices. Without Your cooperation, this thesis would not have been possible!

Two of the participating shipping companies are presented below whilst the other wished to remain anonymous.



We are also truly grateful for all the useful information provided by representatives from Cathelco and Cathwell, and from a very helpful Senior Chief Engineer.

Parts of the laboratory analyses in this thesis have been generously financed by scholarship funds, for which the authors are very grateful.

- A.H. Lindfors Stipendiefond
- Chalmers Mastercard scholarship
- Stiftelsen Sveriges Sjömanshus
- Svenska Sjömannas Sällskapet

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SAMMANDRAG

Sjökylvattensystemet ombord på ett fartyg är avgörande för dess framdrift. Utan ett fungerande sjökylvattensystem äventyras säkerheten; framdriften och all utrustning som är beroende av kylning skulle överhettas, och de flesta fartyg är beroende av sjövatten för brandbekämpning. Det är därför nödvändigt att minimera påväxten av musslor och andra arter som kan begränsa flödet i rörsystemet. Det finns flera olika system för detta, och ett av de vanligaste är elektrolysbehandling av sjövattnet, *Impressed Current AntiFouling* (ICAF). Det är en princip som bygger på att frigöra kopparjoner i sjökistan och rörsystemet. Eftersom mussellarver är väldigt känsliga mot kopparjoner, så är metoden effektiv för att förebygga påväxt. Denna studie är gjord för att granska hur mycket koppar och andra tungmetaller som släpps ut i havet från ICAF-system. Prover från sjövattnensystemet ombord på nio fartyg (sju RoPax-färjor, ett RoRo-fartyg och ett tankfartyg) analyserades med avseende på metallinnehållet. Resultaten visade att kopparutsläppen från ICAF-system var betydligt högre, med ett medianvärde på 42,7 µg/l, än de värden som gavs från tillverkarna, vilket var 2 µg/l. Mängden av koppar som släpps ut i närmiljön på grund av elektrolysbehandlat sjövattnet var, beroende på fartyg, mellan 74–182% jämfört med utsläppen av koppar från fartygens bottenfärg. Slutsatsen från denna studie var att man måste ta hänsyn till kopparutsläppen från elektrolysbehandlat sjövattnet när fartygs miljöpåverkan beaktas.

Nyckelord: elektrolys, MGPS, ICAF, kopparutsläpp, sjövattnenkylning, musslor, påväxt, tungmetaller, fartyg

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ABSTRACT

The seawater cooling system onboard a vessel is essential for propulsion and operation. Without a functioning seawater cooling system, the vessel's safety will be compromised; all equipment dependent on cooling would overheat, and most vessels also rely on seawater for firefighting. Therefore, it is crucial to minimise the settling of mussels and other biofouling species that reduce the water flow inside the pipework. There are several different treatment methods to use, and one of the most common is Impressed Current Anti Fouling (ICAF). ICAF relies on electrolytic release of copper ions into the sea chest and seawater pipework. As mussel larvae are very sensitive to copper ions, the method is efficient to prevent growth inside the pipes. This study aimed to investigate the amount of heavy metals, especially copper, emitted to the sea from ICAF systems. Samples from the seawater cooling system onboard nine ships (seven RoPax ferries, one RoRo-vessel and one tanker) were analysed with respect to metal content. The results revealed that the copper emissions from ICAF were significantly higher, with a median value of 42,7 µg/l, than the concentration of 2 µg/l given by the manufacturers. Depending on the vessels, the environmental load of copper from ICAF was ranging from 74-182% of the load from the vessels' antifouling paint. The conclusion was that the copper load caused by ICAF-treated seawater must be accounted for when considering the emissions caused by ships.

Keywords: electrolysis, MGPS, ICAF, copper emissions, seawater cooling system, mussels, heavy metals, vessels

TABLE OF CONTENTS

1	INTRODUCTION.....	1
1.1	Background.....	2
1.1.1	Biofouling and spreading of Non-Indigenous Species.....	2
1.1.2	Niche areas and antifouling strategies.....	2
1.1.3	Marine growth protection systems for niche areas.....	3
1.2	Aim of the study	4
1.3	Research questions	4
1.4	Delimitations	4
2	THEORY.....	5
2.1	Seawater cooling systems.....	5
2.1.1	Seawater cooling system construction and characteristics.....	6
2.1.2	Box water cooling systems.....	7
2.2	Different types of MGPS	7
2.3	ICAF system operation and working principles	8
2.4	Environmental conditions and biofouling species and types.....	10
2.4.1	Microfouling.....	10
2.4.2	Blue mussels.....	11
2.4.3	Barnacles	11
2.4.4	Seawater temperature fluctuations around Sweden	11
2.5	Modeling of environmental concentrations of metals from ICAF systems.....	12
2.6	Predicted No Effect Concentrations regarding copper and zinc.....	13
3	METHODS.....	14
3.1	Vessel selection	14
3.2	Sampling.....	14
3.2.1	Sample kit and sampling procedure	15
3.2.2	Questionnaire	15
3.3	MAMPEC.....	16
3.3.1	Case study I.....	20
3.3.2	Case study II.....	21
3.4	Calculations of annual copper release	22
3.4.1	Anode loss of mass between service intervals	22
3.4.2	Calculation of copper emissions based on chemical analysis versus manufacturers' recommendations	22
3.4.3	Copper emissions on a global scale.....	23
3.5	Economic aspects	23
4	RESULTS.....	24

4.1	Estimated load of copper from ICAF systems compared to other sources of copper to the marine environment in a type port	25
4.1.1	ICAF versus antifouling paint (Case study I).....	25
4.1.2	ICAF and antifouling paint comparison in a type port (Case study II).....	26
4.2	Calculated annual copper emissions.....	29
4.2.1	Copper emissions based on exchange interval	29
4.2.2	Calculated copper emissions based on sample analysis.....	30
4.2.3	Calculated copper emissions based on manufacturers' statements.....	31
4.2.4	Estimated copper emissions on a global scale	31
4.3	Economic factors	32
5	DISCUSSION	33
5.1	Environmental load modeling and case studies in MAMPEC	33
5.2	Total copper emissions caused by ICAF	34
5.3	Global emissions discussion.....	35
5.4	How does the load of copper from ICAF systems compare to available EQS?.....	35
5.5	The seawater temperature's effect on the cooling system and copper dosage adjustment	36
5.6	Estimated anode lifetime	36
5.7	The economical factor	37
5.8	Method and procedure discussion	38
5.8.1	Sample analysis discussion	39
5.8.2	Design of the questionnaire.....	40
5.8.3	Aspects that can affect the copper levels	40
6	CONCLUSION	41
6.1	Recommendations for further research.....	41
6.1.1	Box water cooling systems and ICAF.....	42
6.1.2	Efficiency of ICAF systems at 2 µg/l.....	42
7	REFERENCES.....	43
	APPENDIX I - Other MGPS alternatives	1
	APPENDIX II - Instructions	1
	APPENDIX III - Questionnaire	1
	APPENDIX IV - ALS Analysis result	1

LIST OF FIGURES

Figure 1. Overview of different pollution sources from vessels (Moldanová et al., 2018)	1
Figure 2. Pipe exposed to heavy fouling by mussels (©Evac, n.d.).....	2
Figure 3. General seawater system overview. Some vessels have a combined HT/LT system for the main engine, and some use seawater instead of a main engine LT system. Firefighting and freshwater generation systems are not included (Kuiken, 2012)	5
Figure 4. Seawater/LT- water cooler.....	6
Figure 5. Electrolysis (Baker, 2012)	8
Figure 6. Generalized installation of the ICAF system in a sea chest (Baker, 2012)	8
Figure 7. Strainer-mounted anodes (Baker, 2012)	9
Figure 8. The release of ions in an active respective inactive sea chest	10
Figure 9. Graph displaying the variations in the seawater temperature during 2020 (SMHI, 2021).....	12
Figure 10. The complete sample kit	15
Figure 11. MAMPEC Environment	17
Figure 12. MAMPEC Compound component.....	17
Figure 13. MAMPEC Emission component	18
Figure 14. MAMPEC Case study I, scenario 1-3 particulars	20
Figure 15. MAMPEC Case study II, scenario 1-3 particulars	21
Figure 16. The average levels of copper and zinc in the ICAF-treated seawater. The average value is displayed as the “x” and the median value is represented by the horizontal line within the box.	24
Figure 17. Copper emissions from ICAF and antifouling paints	26
Figure 18. Copper loads from ICAF compared to antifouling paint.....	27
Figure 19. PEC of copper in sediment from ICAF, MAMPEC Case study II	28
Figure 20. PEC of copper in sediment from antifouling paint, MAMPEC Case study II.....	28
Figure 21. Distribution of anode exchange interval between vessels	29
Figure 22. Active adjustment of current on the ICAF system. None of the vessels actively adjusted according to location.....	30
Figure 23. Salt particles (blue dots) will not pass the membrane (red line), but water will pass through. Left side of red line is inside the cell (Nelson, 2017)	1

LIST OF TABLES

Table 1. Summary of the different MGPS characteristics (Grandison et al., 2011; Growcott et al., 2017; Joyce et al., 2019; Rubio et al., 2015)	7
Table 2. Copper anode costs	10
Table 3. Engine power, type and size of vessels in this study	14
Table 4. MAMPEC size categories and number vessels per category	19
Table 5. Copper released based on change interval	29
Table 6. Based on data from onboard sampling.....	30
Table 7. Emissions according to the manufacturers' stated value	31
Table 8. Global copper emissions	31
Table 9. Economical comparison	32
Table 10. Comparison PNEC and PEC from MAMPEC Case study II.....	35
Table 11. Estimated anode lifetime.....	37

LIST OF EQUATIONS

Equation 1. Seawater discharge per vessel calculations for Category I and V	19
Equation 2. Released copper per year	22
Equation 3. Copper emissions based on analysis and manufacturers' recommendations	23
Equation 4. Estimated anode lifetime	37

ACRONYMS AND TERMINOLOGY

Antifouling	Antifouling systems on vessels are used to control or prevent the growth of organisms e.g. on the vessels hull.
Auxiliary Engine	An engine connected to a generator, which supplies the vessel with electricity.
Biocide	A substance with potential to kill living organisms.
Biofouling	Growth of micro- and macroscopic organisms, e.g. bivalves or barnacles on submerged surfaces such as ship hulls and sea water systems.
DWT	Deadweight Tonnage. A measurement on the total weight a vessel can carry, including cargo, fuel, passengers, crew, provisions, ballast, and freshwater.
Dry-dock	Dry-dock is a floating dock, a common device at shipyard for drying vessels during maintenance and repair.
ECA	Emissions Controlled Area
EQS	Environmental Quality Standards
HT-system	A high temperature cooling water system used for cooling onboard.
ICAF	Impressed Current Anti-Fouling, a Marine Growth Prevention System based on electrolysis to release copper ions into the seawater.
IMO	International Maritime Organization
LT-system	A low temperature cooling water system used for cooling onboard.
Main Engine	The engine, or engines, used onboard a ship for propulsion.
MAMPEC	A marine antifoulant model to predict environmental concentrations. Developed to predict environmental concentrations for the exposure assessment of antifoulants in harbours, rivers, estuaries, and open water.
MARPOL	International Convention for the Prevention of Pollution from Ships. The MARPOL convention includes regulations to prevent and minimize the pollution from ships.
MGPS	Marine Growth Prevention System
<i>Mytilus edulis</i>	Latin name of the bivalve, blue mussel.
Niche Areas	Areas on a vessel which are prone to severe biofouling, including but not limited to sea chests, internal seawater pipework, chain boxes and rudder pins.
NIS	Non-Indigenous Species
PEC	Predicted Environmental Concentration
PNEC	Predicted No Effect Concentration. A concentration of a certain substance, describing the threshold at which the substance concentration has no harmful effects.
RoPax-vessel	Roll-on/Roll-off Passenger vessel. A form of RoRo-vessel which loads both passengers and wheeled cargo, for instance trucks, cars, trailers et cetera.
RoRo-vessel	Roll-on/Roll-Off vessel. Ships designed to carry wheeled cargo such as cars, trucks, trailers et cetera.
Sea Chest	Cavities on the ship's hull where the seawater is pumped into the consumers, such as heat exchangers, evaporators and firefighting systems.

SECA	Sulphur Emissions Controlled Area
SMHI	Swedish Meteorological and Hydrological Institute (Sveriges Meteorologiska och Hydrologiska Institut)
SOLAS	Safety Of Life At Sea, is an international maritime agreement, which sets the minimum requirements for the safety equipment, construction and operation for the vessel.
Transducer	A device that converts an energy form into another.
VFD	Variable Frequency Drive, a control system which regulates the frequency, and therefore the speed of pumps et cetera, allowing the flow to be adjusted.

1 INTRODUCTION

In 2015 the United Nations (UN) agreed on 17 Global Goals, or *Sustainable Development Goals*, SDG, for a sustainable future. The aim was to create a better world by 2030, with significant focus on a sustainable future and dealing with climate change. While all the Global Goals are connected to the shipping industry at some point, the most relevant SDG is 14 *Life below water*, which targets pollution, acidification and overfishing of the sea, as well as the protection and conservation of marine ecosystems (United Nations, 2015).

Recently, the Swedish Parliamentary Committee Miljömålsberedningen published an interim report *Havet och människan*, (The sea and man) which suggests strategies on how to preserve and use the sea and the marine resources in a sustainable way. The report addresses the environmental impacts that shipping and ships contribute to. Further, it is concluded that the environmental aspect of the shipping industry's impact on the marine environment and ecosystems has a tendency to “slip through the net” during decision-making (Miljömålsberedningen, 2020).

Today, the shipping industry has a focus on reducing the climate and environmental footprint (International Maritime Organization, n.d.). Pollution from ships, regarding both air, water and solid waste, is regulated in the *International Convention for the Prevention of Pollution from Ships* (MARPOL). The different systems onboard ships that in some way have an impact on the environment can be observed in Figure 1. This thesis will focus on the seawater used for cooling onboard and how the antifouling-treated seawater that is being discharged back to the sea affects the marine environment.

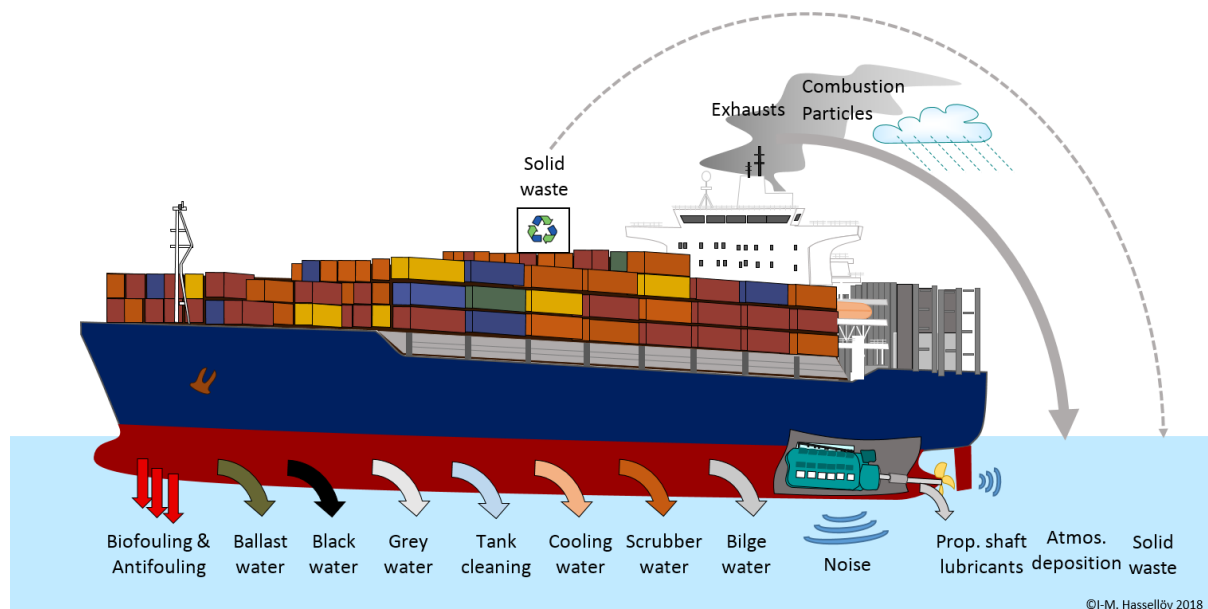


Figure 1. Overview of different pollution sources from vessels (Moldanová et al., 2018)

1.1 Background

Practically all vessels are dependent on seawater for cooling. The propulsion of a modern merchant ship generates excess heat from engines, generators, reduction gears, compressors et cetera which needs to be diverted. The use of seawater is practical since it is a practically endless source of relatively low-tempered water. The seawater systems differ from vessel to vessel, from large systems with several heat exchangers and an extensive pipework, to smaller systems where the seawater is primary used to cool a second cooling system, which consists of treated freshwater in a closed circuit. The latter is called a Low Temperature (LT) system and is used in modern vessels to minimize the internal pipework, therefore lowering corrosion and blockade risks in the seawater cooling system (Kuiken, 2012, Chapter 10).

1.1.1 Biofouling and spreading of Non-Indigenous Species

All surfaces that are submerged in water will be exposed to biofouling. The fouling process begins with a "slime layer" consisting of algae and bacteria, and then develops to more sessile species such as barnacles and mussels (Prendegast, 2010). Biofouling effects on vessel performance are well known; the increased water resistance due to biofouling on the ship hull increases the ship's fuel consumption and thereby emissions. It also implies increased maintenance costs and safety risks. Biofouling is also a significant contributor to the spread of Non-Indigenous Species, (NIS) (Grandison et al., 2011; Growcott et al., 2017). NIS can pose a severe threat to the marine biodiversity, as well as the local fishing and tourism industries in the ecosystems it invades. It is often very costly and practically impossible to try to suppress the invasive species (Joyce et al., 2019). It is therefore important from both economical, operational, environmental and safety aspects to keep the biofouling to a minimum.

1.1.2 Niche areas and antifouling strategies

A significant issue with the use of seawater onboard is the biofouling that occur in niche areas such as the sea chests and seawater piping systems (Figure 2). In comparison, a ship hull is usually protected with an antifouling paint to minimize growth, but due to the complex structure and seawater flow, antifouling paint is not efficient enough to prevent biofouling in sea chests (Coutts & Dodgshun, 2007; Grandison et al., 2011). Due to the limitation of sunlight in sea chests and seawater pipework, there will be no photosynthesizing organisms such as algae. However, the darkness and flow of seawater is an ideal environment for the blue mussel (*M. edulis*) and barnacles, which lives by filtering the surrounding seawater (Anderberg Sternö & Francis, 2007, n. trans; Günther, 1987, n. Trans.; Prendegast, 2010).



Figure 2. Pipe exposed to heavy fouling by mussels (©Evac, n.d.)

Biofouling organisms, such as the blue mussel larvae, settle in the vessels piping systems and sea chests, forming colonies of mussels, which are straining the flow and eventually leads to a blockade (Figure 2). This compromise both the operation and safety of ships by causing the engines to overheat, endangering the vessel's manoeuvrability. The firefighting capability is also jeopardized since many vessels rely on seawater for the firefighting systems onboard. Extra maintenance has to be carried out as well, which is time-consuming and therefore an economical factor to consider (Grandison et al., 2011; Growcott et al., 2017). The *International*

Maritime Organization (IMO), has published guidelines that recommend that sea chests should be complemented with a Marine Growth Prevention System (MGPS) to prevent biofouling in the sea chest and the internal pipework (IMO, 2011).

To prevent biofouling, different antifouling methods are used (Finnie & Williams, 2010; Growcott et al., 2017). They are often based on a toxic substance, such as copper, which is released into the sea either by antifouling paints and/or electrolysis MGPS, also known as Impressed Current Anti-Fouling (ICAF) (Finnie & Williams, 2010; Grandison et al., 2011). There is therefore a trade-off between the efforts to minimize biofouling and spreading on NIS, versus minimizing the toxic substances released from the antifouling. Studies of copper emissions from the shipping industry have so far been focused on copper leaking from antifouling paints on ship hulls. Moldanová *et al.* (2018) estimated the copper release from the shipping industry during 2012, to be 302 tonnes of copper in the Baltic sea. This is more than the total amount of copper released from Sweden in 2006 (239 tonnes), and about a third of the total emissions released into the Baltic sea from all adjacent countries in 2011, which were 886 tonnes. Electrolysis MGPS/ICAF is not accounted for in these numbers (Moldanová et al., 2018).

1.1.3 Marine growth protection systems for niche areas

There are several different systems that can be used to prevent biofouling in niche areas such as sea chests and piping system. There are systems based on the release of toxic substances such as copper electrolysis and chlorine dosage, and systems based on physical treatment, such as thermal treatment, osmosis treatment and ultrasonic treatment (Grandison et al., 2011; Growcott et al., 2017). Copper electrolysis and chlorine-based MGPS are the most common systems used for sea chests (Grandison et al., 2011). The ICAF manufacturer Cathwell estimates that about 90% of the merchant fleet in Scandinavia and Europe use ICAF systems (P. Kittilsen, personal communications, April 13th, 2021). A detailed description of the ICAF system can be found in section 2.3, and descriptions of other MGPS solutions can be found in *APPENDIX I*.

It is well known that copper is an effective agent against biofouling. The first documented use of copper as an antifouling agent was by the Carthaginians and Phoenicians ca 700 BC. The first wide-spread antifouling coating, “McIness” was introduced at the dockyards in Liverpool, UK during the mid-19th century. To this day, copper-based antifouling coating is an effective and practical method. Beside from its use in paints, copper is also used dissolved in the form of copper ions, generated by electrolysis. Electrolysis MGPS, or ICAF, was developed by Cathelco for the British Navy during the 1950s (G. Churm, personal communications, April 15th 2021), and is today a common antifouling method in both the shipping industry and in power plants cooled with seawater (Grandison et al., 2011; Howell & Behrends, 2010; Rubio et al., 2015).

According to the manufacturers’ specification, the required dose of copper to prevent fouling is approximately 2 µg/l seawater (Baker, 2012; Cathwell, n.d.-a; Evac, n.d.-b). However, when operating in real-world conditions, the dissolved copper dose is often set to a much higher value than the manufacturer’s recommendations (Grandison et al., 2011). There are indications that a dose ten times stronger than the manufacturer’s recommendations is required to prevent biofouling from tubeworms (Grandison et al., 2011; Growcott et al., 2017). One marine species known to be sensitive to copper is the blue mussel, whose larvae are significantly affected by increased heavy metal levels, especially copper (Saidov & Kosevich, 2019).

The blue mussel used to be a ubiquitous species in the Northern Atlantic region but appears to have decreased radically during the latest years (Andersen et al., 2016; SLU, 2021).

1.2 Aim of the study

There is very little research on what the electrolysis-treated seawater contains when discharged back to the sea. This study aims to characterize the heavy metal content in the seawater discharged back to the sea, following treatment with ICAF. Samples of treated seawater from different ships operating in and adjacent to Scandinavian waters will be analysed to see if the seawater concentration of heavy metals could be harmful to the marine environment.

1.3 Research questions

- What are typical concentrations of metals, such as copper and zinc, in seawater treated by ICAF?
- What is the estimated load of copper from ICAF systems compared to other sources of copper to the marine environment in a type port?
- How does the load of copper from ICAF systems compare to available environmental quality standards?

1.4 Delimitations

Due to budget and time constraints, a limited number of samples could be analysed. Since the transport of samples, laboratory analyses and contact with ship owners was time consuming, delimitations had to be made to finish the thesis in the required period. As shipping abroad may imply delays and risks of the packages getting stuck in customs, this logistic aspect had to be considered when selecting vessels. Therefore, it was decided to select shipowners and vessels connected or based in Sweden, trading in Scandinavian or North European waters.

The samples were analysed with respect to the metal concentration before and after ICAF treatment. Ships equipped with box water coolers, thereby lacking internal seawater piping for the cooling system were excluded from the study due to practical problems with sampling. However, since many vessels equipped with box water cooling also use electrolysis as an antifouling method, (section 2.3) this thesis's results are also relevant for box water cooling systems.

Due to the global pandemic, some limitations and compromises had to be made. The ships' crew had to take the samples themselves, which reduced the possibility to control the entire sampling procedure. Sampling carried out by different persons adds to the possible sources of variation in the analyses. The diversity of different ships sampled was also compromised since less shipowners had the possibility to contribute.

The contacted shipowners were listed on a document that was based on the shipowner contact details at *Sjöfartens Utbildnings Institut*, SUI. SUI is an educational institute that provides internships for students at the marine programmes in Sweden and therefore have several shipowners with different types of vessels listed on their website¹.

¹ <https://www.sjofart.org/studerande/kontaktuppgifter-rederi/>

2 THEORY

A ship's seawater cooling system is complex (Figure 3) and differs greatly from vessel to vessel. Normally there are at least two systems or more to provide redundancy, depending on the vessel size and number of engines (Kuiken, 2012). Information regarding construction and technical functions of both the seawater system as well as MGPS systems are to a larger extent available in technical reports, manuals, and descriptions from the manufacturers and to a lesser extent in scientific literature.

2.1 Seawater cooling systems

Practically all vessels depend on seawater in some form, mainly for cooling purposes, but also firefighting, freshwater generation and ballast. The seawater systems differ a lot between vessels depending on size, engine power output, type of vessel, and the age of the vessel. Traditionally, seawater was used to cool most parts in the engine room, from the engines (charge air, Lubrication Oil (LO), High Temperature (HT) cooling water) to compressors, gear boxes and steam condensers. However, despite the practically endless source of relatively low-tempered water, most modern ships have minimized the seawater system onboard in favour of a Low Temperature (LT) cooling water system (Figure 3). Seawater has high mineral content, which, when it is heated, leads to crystallization of minerals on surfaces, reducing heat transfer efficacy and increasing the risk of blockades. Seawater is also aggressive on piping materials, with increased corrosion as a result (Kuiken, 2012).

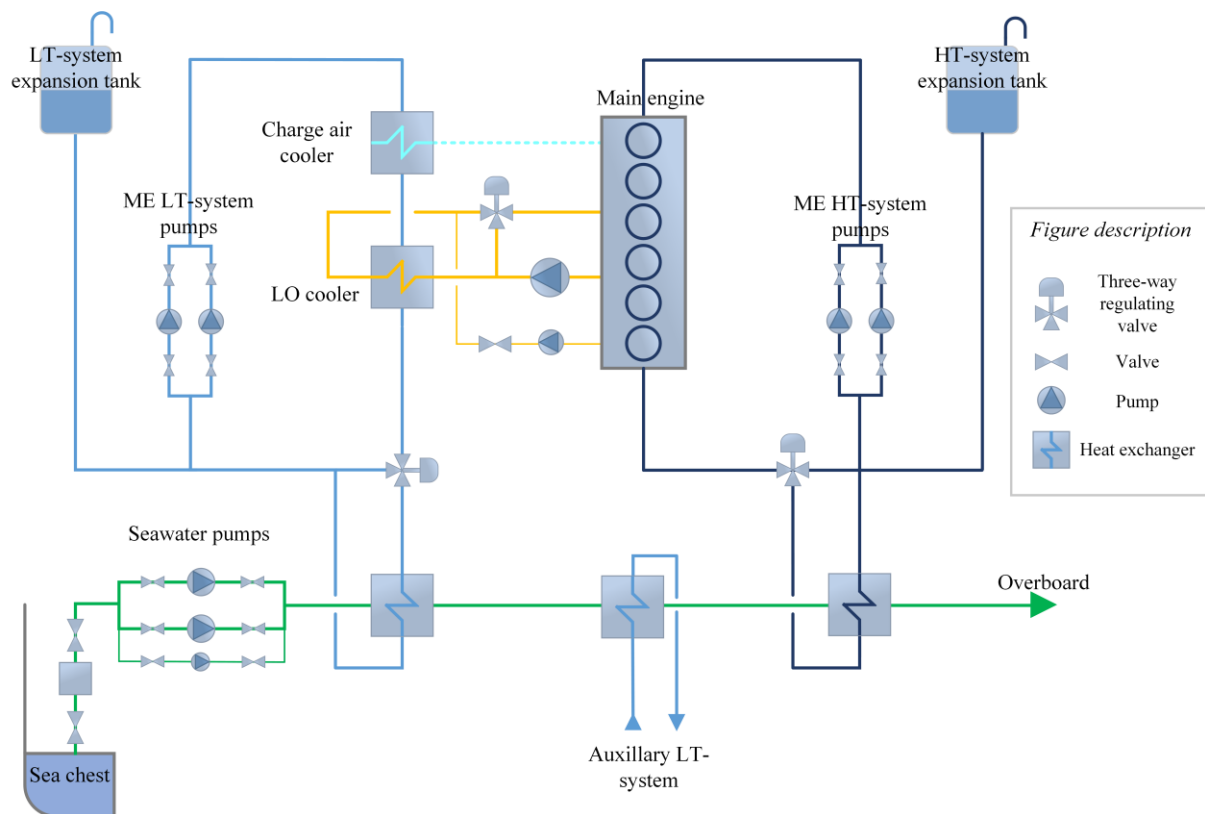


Figure 3. General seawater system overview. Some vessels have a combined HT/LT system for the main engine, and some use seawater instead of a main engine LT system. Firefighting and freshwater generation systems are not included (Kuiken, 2012)

2.1.1 Seawater cooling system construction and characteristics

Figure 3 shows a generalized seawater cooling system on a modern vessel. The seawater system (Figure 3, coloured green) is taken from the sea chest, through a filter, and then pumped into the heat exchangers before it is finally discharged back to the sea. Normally, the system is equipped with at least two main seawater pumps, one running and one stand by, to create a redundant setup. There is also a smaller auxiliary pump to provide flow to the auxiliary consumers when the vessel's main engine/main engines are stopped. Most seawater systems have at least two sea chests, one located higher than the other, to be able to switch from low to high suction to allow for altered water inlet depth. This can be applied when the vessel enters a port with shallow water; by using the high sea chest, sediment can be prevented from entering the system (Kuiken, 2012).



Figure 4. Seawater/LT-water cooler

2.1.1.1 Seawater flow control

The seawater pumping capacity is normally dimensioned to maintain cooling capacity with main and auxiliary engines at full load with a seawater temperature of 32° C (Lee et al., 2014). However, since several vessels normally do not operate at these extreme conditions, especially not in polar or temperate regions, like the waters around Sweden (section 2.4.4), the LT-water will have to be bypassed from the cooler by the Three-way valve (Figure 3). This leads to a low energy efficiency, since a lot of energy is consumed to keep the unnecessary high flow. However, a solution that is becoming increasingly common is to use Variable Frequency Drives (VFD), which allows for the pump speed to be adjusted by adjusting the frequency, and thereby, the seawater flow. According to a study by Lee *et al.* (2014), an energy reduction up to 79% for the cooling water system can be achieved, both at full and part loads, given that the seawater temperature is below 32° C.

2.1.1.2 Low Temperature system

The main engine low temperature system (Figure 3, coloured light blue) consists of two pumps, one running and one standby for redundancy. This system is used to cool down the incoming air to the main engine, the charge air, and then to keep the lubrication oil system within its operational temperatures. The lubrication oil temperature is regulated by a three-way valve which can be seen in Figure 3. The low temperature cooling water is then cooled by seawater (Figure 4), and the temperature is regulated by a three-way valve on the low temperature system. Typically, there are two main engine low temperature water coolers to ensure safe operation even if technical problems occur with one of the coolers. Normally, there is also an auxiliary low temperature system separated from the main engine system, which are used for cooling auxiliary engines, compressors, gear boxes et cetera (Kuiken, 2012).

2.1.1.3 High Temperature system

The main engine high temperature system (Figure 3, coloured dark blue) is used to cool down the engine from the heat generated by combustion. Apart from the higher temperature, the system characteristics are similar to the main engine low temperature system, with two pumps, a three-way valve for temperature regulation and two coolers for redundancy (Kuiken, 2012).

2.1.2 Box water cooling systems

A solution that eliminates the internal seawater cooling system is box water cooling. The seawater is then only used to cool a heat exchanger mounted in the sea chest or on the hull, which itself cools a low temperature system serving the different systems onboard (Kuiken, 2012). Currently, box cooler systems are only applicable on smaller vessels, but according to some box cooler manufacturers, box water coolers can be used on ships with an engine power up to 30 000 kW. A major downside is that the vessel must be dry-docked to clean the cooler(s). It is therefore essential to have a working and effective MGPS to prevent unnecessary and costly dry-docks just to clean the cooler (Aijjou et al., 2018; Młynarczak, 2013).

2.2 Different types of MGPS

There are several different MGPS used to prevent biofouling in niche areas. The most common systems and the main technical aspects are described in Table 1. Since this thesis focuses on the ICAF system, it is described in detail in section 2.3, whilst a more detailed description of the other types of MGPS can be found in *APPENDIX I*.

Table 1. Summary of the different MGPS characteristics (Grandison et al., 2011; Growcott et al., 2017; Joyce et al., 2019; Rubio et al., 2015)

MGPS	Working Principle	Advantages	Limitations
Copper Electrolysis (ICAF)	Biocide/toxin	A well-known system in use both on vessels and in shore-based industry. It can be co-installed with anodes to prevent corrosion in the seawater system.	The vessel must be dry-docked in order to exchange the anodes (depending on the system). Releases copper ions into the marine environment.
Chlorine dosing	Biocide	A relatively cheap, well-known system that is common in the shipping industry and for industrial applications.	May increase corrosion of seawater piping can cause damage to the marine ecosystem.
Osmotic Shock	Induces freshwater to lower the salinity and therefore induce mortality to the biofouling via osmotic shock.	Simple system, freshwater can be generated onboard. Environmentally friendly.	Not very effective, requires much freshwater and long exposure time (up to several weeks depending on biofouling species).
Thermal Shock	By heating the relevant areas, either by recirculating the seawater or by inducing steam.	Environmentally friendly, capable of killing most biofouling species.	Requires a large amount of energy for heating. When using steam, the surfaces must be dry (Requires dry-dock or other measures to evacuate the seawater).
Ultrasonic	Acoustic shockwaves cause a mortal electro-hydraulic shock onto the biofouling species.	Environmentally friendly causes no emissions by itself. Easy to install (no dry-dock required).	It may need to be installed together with another MGPS to be effective, not very common. May increase the spread of NIS due to low efficiency.

2.3 ICAF system operation and working principles

In electrolysis, a Direct Current (DC) is used to create a chemical reaction between two electrodes. An electrode is an electron conductor used to create electrical contact with non-metallic materials such as electrolyte, ionized gas, or vacuum. The electrode where the positive metal ions are formed and enters the solution is called the anode, and the other electrode which receives the ions is called the cathode (Figure 5) (Larsson, 2008).

To use this principle for an antifouling purpose, the anode is one or multiple copper rods mounted either in the sea chest (Figure 6) or inside the internal pipework (Figure 7) (Grandison et al., 2011), and the sea chest respective piping system are the cathode. Due to the salinity, sea water is a potent electrolyte which means that a relatively low DC voltage is required to deliver the necessary current for the electrolysis. According to a contacted Chief Engineer, the current in the electrolysis system is raised when sailing in waters with lower salinity and then lowered respectively when sailing waters with higher salinity levels. This is adjusted automatically by the control unit in order to provide the same copper dosage regardless of salinity in the sea.

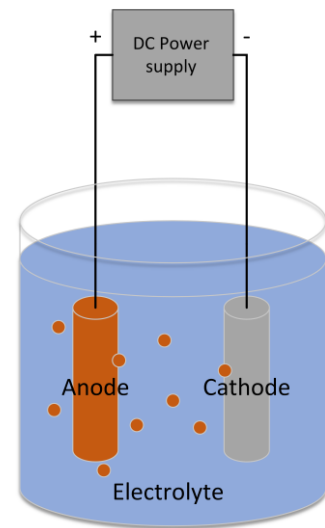


Figure 5.
Electrolysis (Baker, 2012)

The electrolysis causes copper ions to be released into the seawater preventing biofouling. According to Cathelco and Cathwell, two manufacturers of electrolysis-based MGPS, the required dosage of copper ions is only around two parts per billion (Baker, 2012; Cathwell, n.d.-a; Evac, n.d.-b). However, there are indications that a significantly higher current than recommended by the manufacturers is necessary to provide efficacy in real world operating conditions (Grandison et al., 2011; Growcott et al., 2017), which would lead to the copper concentrations in the sea cooling water being higher as well.

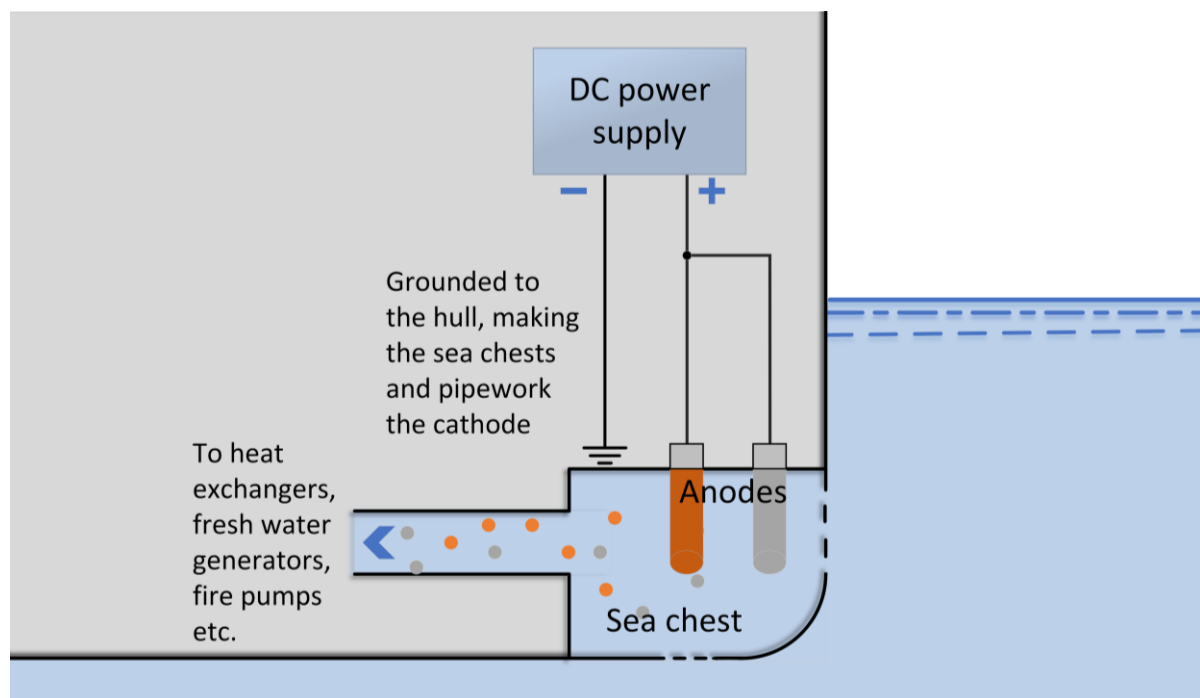


Figure 6. *Generalized installation of the ICAF system in a sea chest (Baker, 2012)*

When the anodes are mounted in the sea chest, they can only be replaced when the vessel is dry-docked, but with strainer-mounted anodes the exchange can be done at sea (Baker, 2012). According to Cathwell, the anodes are normally consumed to about 90% or more when replaced (Cathwell, n.d.-a).

Vessels equipped with box water cooling can also be equipped with an ICAF system to prevent growth on the heat exchanger. Then the anodes are mounted in the sea chest similar to vessels with conventional seawater cooling (Figure 6) and require drydocking to be replaced (Evac, n.d.-a). These anodes are normally consumed to about 80% or more when replaced (Cathwell, n.d.-a).

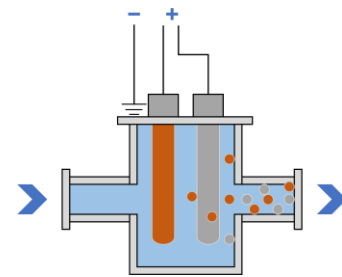


Figure 7. Strainer-mounted anodes (Baker, 2012)

The ICAF system is normally constructed and tuned based on the vessels' maximum seawater flow, which leads to unnecessarily high copper concentrations at lower flows. However, Cathwell has two solutions which allows the copper concentration to be adjusted according to the actual seawater flow. One system is based on a dynamic copper dosing, where the system measures the seawater flow, and allows for the dosage to be adjusted steplessly. The other system is based on a relay or switch connected to a seawater pump or a flow meter, which alters the dosing between a preadjusted high- or lowlevel (Cathwell, n.d.-a, 2020).

Normally, the ICAF system is also equipped with anodes for corrosion prevention. These anodes are made of different materials depending on the internal pipework material. In systems that use a ferrous metal for the seawater piping, an aluminium anode is used. For copper-nickel (CuProNickel) based systems, the anode is instead made of iron (Baker, 2012).

The ICAF treatment can be combined with chlorination of the seawater. This has proven to be effective in several cooling systems, both at sea and ashore. Due to the biocide impact, it is not recommendable in open loop coastal facilities where the water exchange is low. However, it can be recommended in closed cooling systems or on ships (Rubio et al., 2015).

According to Cathelco, their ICAF systems are fitted on over 50 000 ships worldwide. The technology is scaleable and is therefore also available on smaller yachts, as well as larger merchant vessels (Evac, n.d.-b). In comparison, the total commercial fleet of vessels of 100 gross tonnes and above, consisted of 98 140 ships at the beginning of 2020 (United Nations Conference on Trade and Development, 2020).

As described in section 2.1.1, a vessel's seawater system is equipped with at least two or more sea chests. Normally, there are anodes mounted in all sea chests. However, unless the ICAF is adjusting to the seawater flow, the release of copper ions will continue at the same rate (at the tuning for the maximum flow) regardless if the sea chest is in use or inactive (Cathwell, 2020). This leads to that the copper concentration in inactive sea chests will be high, since there is no flow rate, as displayed in Figure 8.

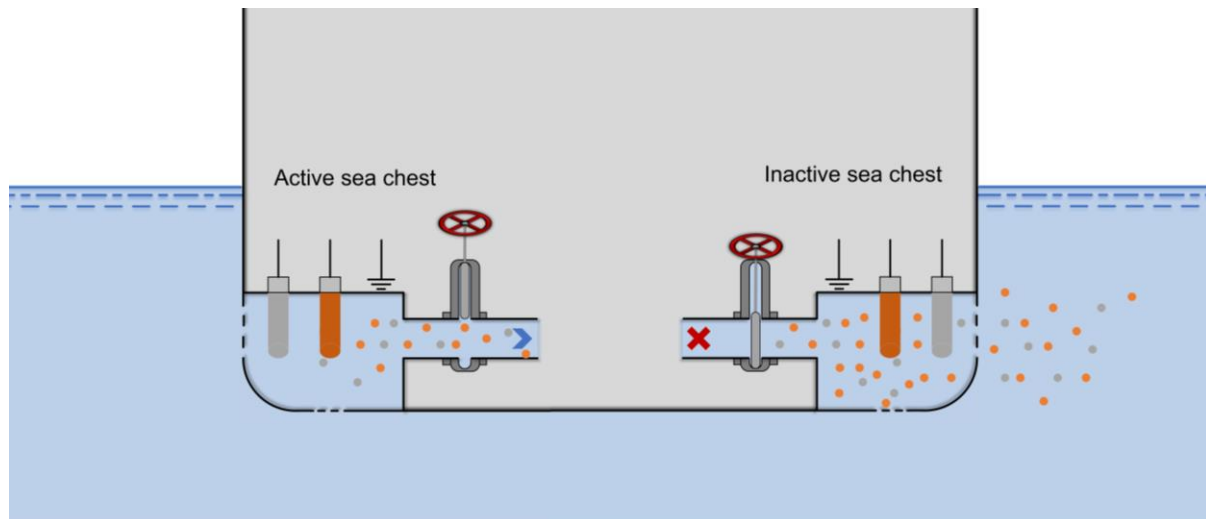


Figure 8. The release of ions in an active respective inactive sea chest

Three price examples for the copper anodes from Cathwell are displayed in Table 2 (P. Kittilsen, personal communications, April 13th, 2021). The price presented is only applicable for the material cost i.e. the anodes; labour costs regarding removing and installing, shipment and dry-dock costs are excluded. The price is applicable for spare anodes; when installing a brand-new system, the anode cost is lower.

Table 2. Copper anode costs

Type of anode	Size, Length*Diameter	À price
Copper	10*1,2 dm	2 160 €
Copper	7,0*1,0 dm	1 170 €
Copper	2,8*0,8 dm	520 €

2.4 Environmental conditions and biofouling species and types

Since this report focuses on the biofouling occurring in niche areas and primary sea chests and the seawater cooling pipework, the most relevant species for these areas will be described. Photosynthetic biofouling species, however, will be excluded since the dark environment in the piping systems and sea chests will not allow for any photosynthesis.

2.4.1 Microfouling

Fouling of microorganisms on hard structures in marine environments begins in minutes after the structure is submerged in water. The microfouling consists of bacteria which form a biofilm, only about a hundred micrometers thick. Even if the microfouling only consists of a thin film, it causes several issues on vessels. From increased flow resistance of the hull, to increased corrosion, to a less effective heat transfer in the sea water coolers. Few MGPS are effective against this type of biofilm fouling since its resistance against biocides and antibiotics is significantly higher compared to other fouling types. Marine biofilm can even develop on top of biocide-based antifouling coatings (Dobretsov, 2010).

2.4.2 Blue mussels

The blue mussel (*M. edulis*) has always been a targeted species when it comes to biofouling, especially concerning niche areas. The seawater flow, as well as the rugged surfaces and angles, provides good conditions for the blue mussel, which lives by filtering seawater (Anderberg Sternö & Francis, 2007; Günther, 1987; Prendegast, 2010). The forming of colonies is typical for mussels, which leads to that the seawater flow is strained, both internally in the piping systems and sea chests and externally on the hull (Grandison et al., 2011; Growcott et al., 2017). The spawning and settling of blue mussel larvae are heavily influenced by the seawater temperature (Seed & Suchanek, 1992), and the reproduction begins when the seawater temperature is around 10-12°C (Pleijel, 2014). Hence, from a seawater cooling system perspective, the variations in seawater temperature are important both for the required flows and when the fouling pressure of blue mussels can be expected to be the highest. The blue mussel larvae are sensitive to copper, which is one reason why copper-based antifouling is widely spread. A copper concentration of 4-10,8 µg/l was proven to induce mortality for half the population of mussels (Saidov & Kosevich, 2019). The blue mussel population has decreased significantly in Scandinavian waters, but the reason for this is not yet completely known (Andersen et al., 2016; SLU, 2021).

2.4.3 Barnacles

Another primary fouling species is the barnacle, a sessile crustacean, whose hard shells are difficult to remove once it is established. Normally, the settling of barnacles on ship hulls is prevented by the help of antifouling paints. The barnacle larvae are affected by copper; however, they are not as sensitive as blue mussel larvae. Experiments have shown that copper concentrations of 145 µg/l were capable of inducing mortality in half the population of barnacle larvae (Qiu et al., 2005).

2.4.4 Seawater temperature fluctuations around Sweden

The seawater temperature in Scandinavian waters, varies greatly depending on season (Figure 9). This affects the vessels trading in the area; since the temperature difference between the summer and winter is about 15° C, the efficacy of seawater as a coolant differs greatly on season, therefore requiring higher seawater flows during summertime than the rest of the year. Vessels with adjustable seawater flow can therefore be expected to have a lower flow during late autumn, winter and spring (section 2.1.1.1). The blue mussel's reproduction phase commences at a seawater temperature about 10-12 ° C (section 2.4.2), which around Sweden occurs from the beginning of May to June.

The data presented are retrieved from Swedish Meteorological and Hydrological Institute (SMHI) (SMHI, 2021). Four stations were selected to provide data from different locations around Sweden. The stations were *Vinga SJÖV* (located at the west coast), *Ystad SJÖV* (located on the south coast), *Finngrundet WR Boj*, (located on the east coast), *Strömören SJÖV* (located on the north east coast).

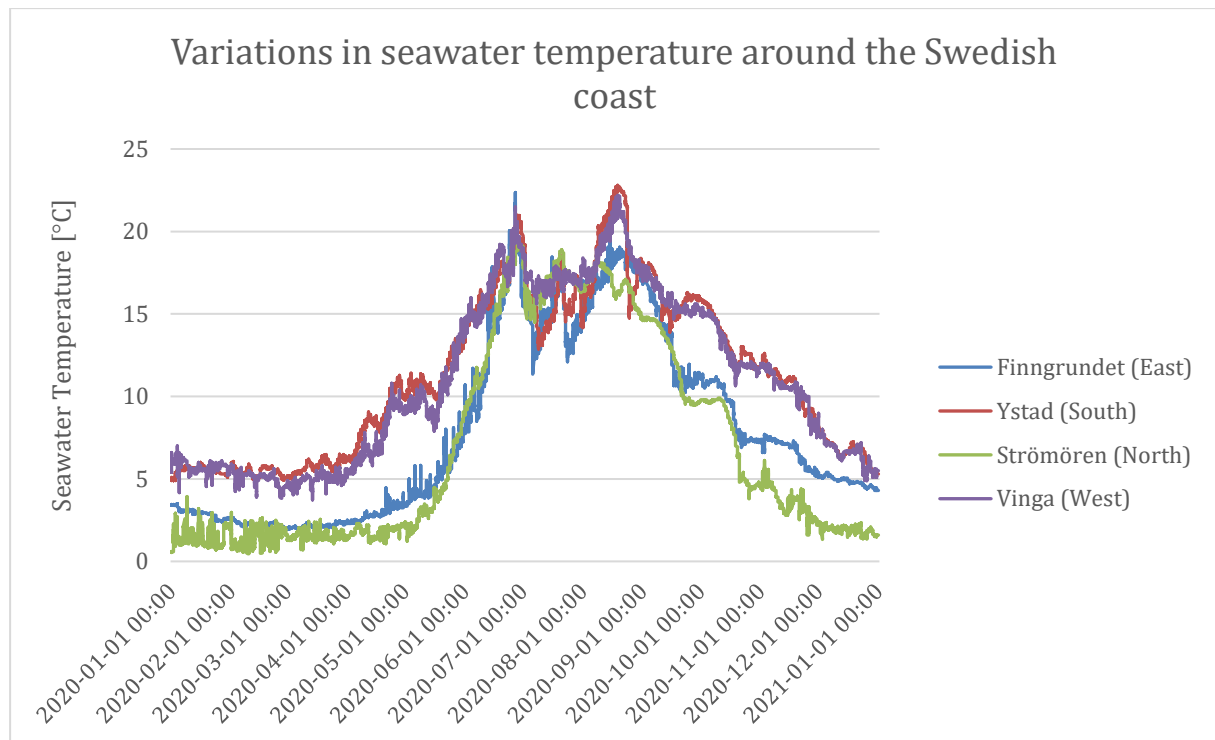


Figure 9. Graph displaying the variations in the seawater temperature during 2020 (SMHI, 2021)

2.5 Modeling of environmental concentrations of metals from ICAF systems

The Marine Antifoulant Model to Predict Environmental Concentrations (MAMPEC) is a 2D integrated hydrodynamic and chemical model. MAMPEC was developed in the early 2000s by Deltares² to estimate how different concentrations of certain substances affect local ecosystems depending on water exchange, currents, geographical characteristics, et cetera. The model used for simulations regarding leach from antifouling coatings is called MAMPEC Antifouling (AF) (Van Hattum et al., 2016).

The software can also be used to assess the ballast water system and the discharge of chemicals in the ballast water, by running the MAMPEC Ballast water (BW) module. The ballast module does not adjust volumes when calculating the ballast discharge, it only accounts for the inserted load from substances in the volume (P. Verdoorn, personal communications, April 7th, 2021). This allows for setting up scenarios with the seawater cooling system, and to investigate the loads from copper originating from the discharged seawater.

The model is available in several different versions that have been created and updated during the last 20 years. Today MAMPEC is used for environmental risk assessment of antifouling substances and is recognized by regulatory authorities in Europe, the United States of America (USA), and other countries. The IMO has used MAMPEC for simulations concerning ballast water discharge (Van Hattum et al., 2016).

² <https://www.deltares.nl/en/>

2.6 Predicted No Effect Concentrations regarding copper and zinc

In order to determine the threshold value where a certain substance will not cause toxicological effects, a PNEC value can be calculated. A common use of PNEC values is when creating environmental risk assessments concerning ecotoxicology in the environment (European Chemicals Bureau, 2003). According to the Swedish Agency for Marine and Water Management's statute book, HVMFS 2019:25, which defines the Environmental Quality Standards (EQS) for Swedish waters, the PNEC value concerning copper is 4,3 µg/l for the Swedish west coast. However, concerning the Baltic Sea, the lower 1,45 µg/l shall be used. Concerning zinc, the PNEC values are 3,4 µg/l for the Swedish west coast and 1,1 µg/l for the Baltic Sea. Regarding the sediment, the PNEC value is 52 µg/g dry weight (dw) for coastal and transition zone waters. However, the natural background concentration of copper in the sediment needs to be accounted for in order to make a correct conclusion (Havs- och Vattenmyndighetens Författningssamling, 2013).

3 METHODS

The research methods applied in this thesis consist of a review of existing literature, chemical characterization of cooling water from onboard sampling, and modelling of concentrations in the environment, with focus on copper. The result is therefore based on articles, results from chemical analyses carried out by ALS Scandinavia AB and supporting data from a questionnaire attached with the sampling instructions. The sample results have also been modelled in MAMPEC to better understand the consequences of the traced metals in the analyses.

The scientific literature was primarily accessed through Web of Science and Scopus. In contrast to the vast number of studies available on antifouling in general, there were few scientifically published studies on specific antifouling methods in cooling systems. Therefore, scientific reports from various universities and technical reports and instructions from manufacturers (for example, Cathelco and Cathwell) were used.

3.1 Vessel selection

Information about the study were sent by e-mail to 22 shipowners based in or connected to Sweden. A total of five shipowners agreed to participate, resulting in nine vessels included in the study, categorized as vessel A-I (Table 3).

Table 3. Engine power, type and size of vessels in this study

Vessels	Vessel type	Vessel length [m]	Seawater flow [m ³ /h]	Engine power [MW]	Seawater flow (m ³ /h) / MW
Vessel A	Ropax ferry	183	160	23	6,9
Vessel B	Ropax ferry	219	180	41,6	4,3
Vessel C	Ropax ferry	183	160	23	6,9
Vessel D	Ropax ferry	111	50	9,8	5,1
Vessel E	Ropax ferry	213	400	30,4	13,2
Vessel F	Oil Tanker	135	50	6,3	7,9
Vessel G	RoRo vessel	232	1300	15,8	82,3
Vessel H	Ropax ferry	155	160	25,7	6,2
Vessel I	Ropax ferry	240	90	33,1	2,7
Median		183	160	23	6,9

3.2 Sampling

Sample kits with bottles, detailed sampling instructions to aid the crew, and a questionnaire to retrieve supporting information were prepared and sent to the shipowners (*APPENDIX II and III*). After onboard sampling by the crew, the samples were sent back to Gothenburg, where subsamples were transferred to smaller bottles and duplicates sent to ALS Scandinavia AB in Luleå for analysis of metals. The analysis package ordered was *V3-a Metaller (19) I förorenat vatten utan uppslutning* (V3-a Metals (19) in polluted water without digestion) (V-3a/LE).

3.2.1 Sample kit and sampling procedure

Acid-cleaned sample bottles provided in the sample kits were ordered from ALS Scandinavia AB. Included in the sample kit (Figure 10) were the following:

- Instructions on how to take the sample (*APPENDIX II*)
- A questionnaire regarding vessel particulars (*APPENDIX III*)
- Two plastic bottles, one for the sample before the MGPS and the other after
- One pair of plastic gloves
- For prompt return after sampling, a return note

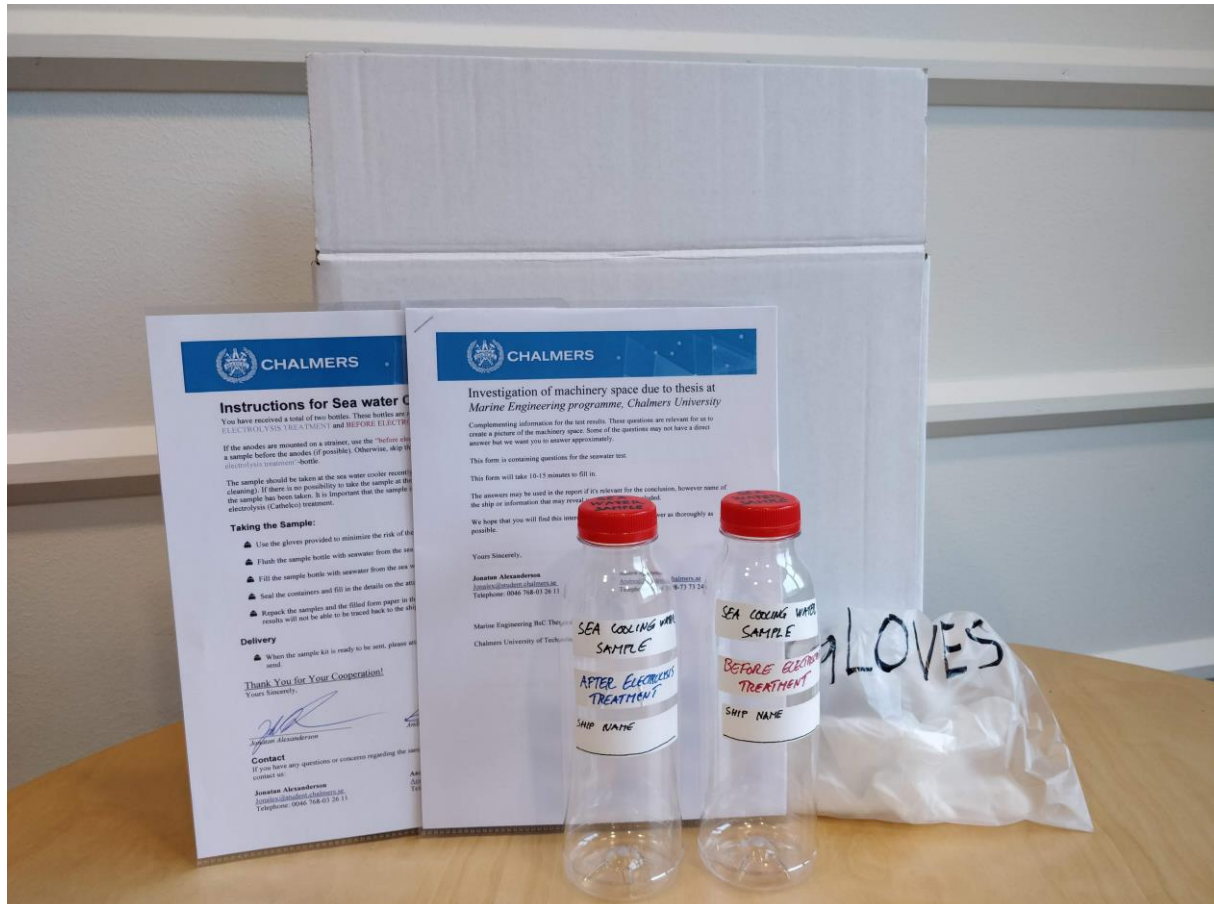


Figure 10. The complete sample kit

Co-author Sjöström had the opportunity to visit one vessel and take the sample by himself. The procedure for sampling were done as according to the sample instructions (*APPENDIX II*), which clearly explains how to perform the sample test procedure and what to think about and where to take the sample. The instructions stated that the sampling point should be before (if applicable) and after the ICAF treatment. It was suggested to take the after-sample at the main sea water cooler if possible.

3.2.2 Questionnaire

The questionnaire consisted of a short description of the aim of study, followed by 26 questions. 30% of the questions were multiple-choice questions, and 70% required a short-written answer. The front page pointed out that the form would provide the authors with an overview of the engine room, take about 10-15 minutes to fill in, and that the ship's name would be excluded

in the thesis. The questionnaire focused on the vessel's seawater system particulars such as flow, pressure, anode numbers and placement in addition to how the vessel operates the treatment of the seawater. The purpose of the questionnaire was to get a better overview and knowledge about the vessel particulars, and to provide necessary data for the thesis.

3.3 MAMPEC

To model the estimated load of copper from ICAF systems compared to other sources of copper, and to compare the load of copper from ICAF systems with available EQS, the simulation software MAMPEC (described in section 2.5) were used. MAMPEC is developed for both assessing the leach rate from antifouling coatings on ships (MAMPEC AF), and for determining environmental loads from substances in the discharged ballast water (MAMPEC BW).

The MAMPEC model consists of three main components: *Environment*, *Compound properties* and *Emission Scenarios*, each handled in individual windows in the software. The *Environment* component (Figure 11) is where the hydrodynamical and geographical conditions for the simulation are adjusted. There are also predefined environments that can be chosen, such as a standard port, shipping lane or marina. One of the selectable standard ports is the OECD EU Commercial harbour. It accounts for hydrodynamic properties, including tidal water, flow, density, in addition to weather conditions (wind), to provide a simulation for an average European harbour. When evaluating the load from biocides, the OECD EU Commercial harbour is used for regulatory purposes. Beside the properties of the harbour included in the *Environment* component, vessel properties of vessels operating and at berth in the harbour are handled in the *Emission* component.

The *Emission* component (Figure 13) is where the size and number of vessels, antifouling paint leach rate, ballast water discharge et cetera is adjusted. There are some predefined cases to be selected in the *Emission* component similar to the *Environment* component. There is a predefined way on how MAMPEC AF calculates the vessels' hull area covered in antifouling paint based on the ships' length, and a pre-set leach rate ($2,5 \mu\text{g}/\text{cm}^3/24\text{h}$) of copper from the antifouling coating. The application factor of antifouling paint is pre-set to 90%, making it possible to determine the copper release from the paint.

The *Compound* component (Figure 12) is where the desired substance is selected. Some of the predefined substances are copper, zinc, and tributyltin (TBT) for environmental load modelling.

Model

- Environment
 - OECD-EU Commercial harbour
- Compound
 - Copper total (example)
- Emission
 - OECD-EU Commercial Harbour...

Run

- Run model & view results
- Multiple run

Import / Export

- Import
- Export
- Report

Description: OECD-EU Commercial harbour

Environment type: Commercial harbour

Reference: ESD-PT21 Table 0.5
Note: According to the EU-TGD the default average marine temperature to be used in the EU countries is 9 °C (ECB, 2003)

Hydrodynamics

Tidal period: 12.41 hour

Tidal difference: 1.5 m

Max. density difference tide: 0.4 kg/m³

Non tidal daily water level change: 0 m

Flow velocity (F): 1 m/s

Layout

Length: x1 1000 m, x2 5000 m

Width: y1 1000 m, y2 500 m

Depth: 15 m

Mouth width: x3 2500 m

Water characteristics

SPM concentration: 35 mg/l

POC concentration: 1 mg/l

DOC concentration: 2 mg/l

Chlorophyll: 3 µg/l

Salinity: 34 psu

Temperature: 15 °C

pH: 7.5

General

Latitude: 50 ° (dec) NH

Cloud coverage: 5 class [0-10]

Sediment

Depth mixed sediment layer: 0.2 m

Sediment density: 1000 kg/m³

Degr. organic carbon in sediment: 0 1/d

Nett sedimentation velocity: 1 m/d

Fraction organic carbon in sediment: 2.85E-002

Wind

Average wind speed: 0 m/s

Fraction of time wind perpendicular: 0 -

Flush

Flush (f): 0 m³/s

Max. density difference flush: 0 kg/m³

Submerged dam specification

Height of submerged dam: 0 m

Width of submerged dam: 0 m

Depth-MSL in harbour entrance: 10 m

Exchange area harbour mouth (below mean sea level): 37500 m²

Calculated exchange volumes (m³/tide)

Category	Value	Percentage
Tidal	7.500E+006	14.65 %
Horizontal	9.166E+006	17.91 %
Density induced	3.452E+007	67.44 %
Wind driven	0.000E+000	0.00 %
Non tidal	0.000E+000	0.00 %
Flushing	0.000E+000	0.00 %
Total	5.119E+007	m³ / tide
	68.25	% / tide

Figure 11. MAMPEC Environment

Model

- Environment
 - OECD-EU Commercial harbour
- Compound
 - Copper total (example)
- Emission
 - OECD-EU Commercial Harbour...

Run

- Run model & view results
- Multiple run

Import / Export

- Import
- Export
- Report

Compound description: Copper total (example)

Compound name: Copper

Molecular mass: 63.5 (g/mol)

Saturated vapour pressure at 20 °C: 0 (Pa)

Solubility at 20 °C: 0.001 (g/m³)

Metal ☐ **Organic** ☐

☒ Copper compound

Kd: 30 (m³/kg)

CAS number:

EINECS number:

Reference:

Figure 12. MAMPEC Compound component

Length class (m)	Surface area (m2)	# Ships at berth (/d)	# Ships moving (/d)	Application factor (%)
50-100	1163	11	0	90
100-150	3231	5	0	90
150-200	6333	5	0	90
200-250	10469	1	0	90
250-300	15640	2	0	90
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Figure 13. MAMPEC Emission component

The OECD EU Commercial harbour was used as a starting point for modelling of copper emissions from ship hulls and ICAF systems for all simulations done in MAMPEC AF and BW. Two cases were studied; *Case study I* was tailored only to compare the proportions of copper emissions between ICAF and antifouling paint of the sampled vessels. The simulation does not consider the probability that all these vessels are located in the very same port at the same time. Therefore, the result of the first case study should not be regarded as a demonstration of the local environmental consequences, but rather as a demonstration on the scale of copper emissions that ICAF systems accounts for relative to antifouling paint. The second case study, *Case study II*, was done to be able to estimate actual environmental loads of copper during realistic harbour conditions (number of vessels, size of the vessels et cetera).

MAMPEC AF includes a pre-set *Emission* model, based on the average size and number of vessels in a type port, the OECD EU Commercial harbour. The simulation handles all vessels moving and at berth during a day (24h), divided in five size categories with a predefined number of vessels in each category. In this thesis, the categories are defined as category I-V. The vessels in this study (Table 3) were distributed into the relevant size categories (Table 4). This enabled MAMPEC AF to estimate the copper load from the vessels antifouling coatings. The moving vessels in the type port in the predefined emission model was not included, since it could not be included in MAMPEC BW when simulating the load from ICAF.

To calculate the daily seawater discharge for category I, it was decided to use the average power of oil tankers up to 5000 deadweight tonnes (dwt). This since oil tankers in this range correlates relatively well to the 50-100m length category defined in MAMPEC. The average engine power for these tankers are 1 174 kW according to the Fourth Greenhouse Gas Study performed by IMO (IMO, 2020).

For category V, it was decided to calculate with an average Suezmax³-sized tanker, which is about 275 metres, ranging between 120-200 000 dwt. The average engine power for a Suezmax tanker is 17 832 kW (IMO, 2020). The engine power, converted to MW, was used together with

³ <https://www.britannica.com/technology/Suezmax>

the seawater flow/MW calculated in Table 3 to provide the seawater discharge [m³/h] for size category I and V (Equation 1).

Equation 1. Seawater discharge per vessel calculations for Category I and V

P	MW	Engine power
\dot{m}	m ³ /h	Seawater discharge
6,9	constant	Median SW flow/MW

$$\dot{m} = 6,9 * P_{MW}$$

The sampled copper concentration used in the case studies and simulations was 42,7 µg/l, which was the median value of the concentrations given by the sample analysis (section 4). This since the concentration of copper in the seawater could not be proven to depend on the vessel type, size or engine power based on the data retrieved in this study.

Table 4. MAMPEC size categories and number vessels per category

Category	Vessel lengths [m]	MAMPEC Predefined vessels	Vessels in thesis	Seawater discharge per vessel in category [m ³ /h]	Estimated total seawater discharge per category [m ³ /24h]
I	50-100	11	0	8	2112
II	100-150	5	2	50	6000
III	150-200	5	3	160	19200
IV	200-250	1	4	290	6960
V	250-300	2	0	123	5904
<i>Total seawater discharge from all categories</i>					40176

When estimating the load from a substance using MAMPEC BW, a total discharged ballast water volume in m³/24h, and the concentration of the substance, in mg/l, shall be inserted. To use MAMPEC BW for sea cooling water discharges and analyses of the copper load it causes, the seawater flow is inserted instead of the discharged ballast water in the *Emission* component, and copper is selected as the *Compound*.

To use the copper concentrations and seawater flows retrieved from the questionnaire and the sample analysis, the seawater flow needs to be combined and the average copper concentration needs to be calculated. However, the average value can be misleading when dealing with data from a limited number of sources with a large variation. In these cases, the median value is preferred since the outliers will not affect the median value, as they would with the average value (Statistiska Centralbyrån, n.d.). Therefore, the median values were used for the MAMPEC simulations.

Since MAMPEC BW requires a total flow and a concentration of the relevant substance in that flow, only the sampled concentration of copper, together with the seawater flow at the time of the sampling, could be used. This means that only the active sea chest was accounted for, and the copper load from inactive sea chests was not included in the results from either of the MAMPEC scenarios.

3.3.1 Case study I

To compare the copper emitted from ICAF treatments with the copper emitted from the antifouling paint, three different MAMPEC scenarios were done, one in MAMPEC AF and two in MAMPEC BW. The scenarios were run with the same number of vessels, harbour conditions and weather to provide the same initial conditions in order to be able to compare the results side by side (Figure 14).

The vessels' seawater flow was combined, and the median copper concentration based on all vessels was calculated for the simulation. A scenario, using the same flow as scenario 2 but with a copper concentration of 2 µg/l, was done. This was to provide an overview of the environmental concentrations from ICAF systems, both the manufacturers' stated value and the actual sampled value, with the environmental concentration that the antifouling paint caused.

<i>Case study I</i>		Location: OECD EU Commercial harbour				
Scenario 1. MAMPEC AF		Vessels				
<i>Antifouling paint</i>		Cat I	Cat II	Cat III	Cat IV	Cat V
Based on the number of vessels in this study		0	2	3	4	0
		Antifouling paint leach rate:				
		2.5 µg/cm ³ /24h				
Scenario 2. MAMPEC BW		Copper concentration in discharged seawater				
<i>Median concentration</i>		0.0427 mg/l				
Cu Conc. And SW flow based on the number of vessels in this study		Total discharge of seawater (Ballast water in MAMPEC)				
		61200 m ³ /24h				
Scenario 3. MAMPEC BW		Copper concentration in discharged seawater				
<i>Manufacturers' concentration</i>		0.002 mg/l				
SW flow based on the number of vessels in this study		Total discharge of seawater (Ballast water in MAMPEC)				
		61200 m ³ /24h				

Figure 14. MAMPEC Case study I, scenario 1-3 particulars

3.3.2 Case study II

Case study II was tailored to estimate realistic environmental copper loads from ICAF systems respective antifouling paints in an average harbour, with the distribution of vessels according to an average European harbour. The *Emission* used in MAMPEC AF was the pre-defined OECD EU Commercial harbour (not to be confused with the *Environment* OECD EU Commercial harbour), which is based on these average values. The number and sizes of the vessels in this pre-defined model are displayed in Table 4. However, the moving vessels in the pre-defined port was not included since they could not be represented in MAMPEC BW. This results in a slight underestimation of the environmental copper loads.

When executing simulations in MAMPEC BW, two values needed to be retrieved to estimate the load of copper in the type port; the combined seawater flow from each vessel in all categories, and the median copper concentration, based on all vessels. As displayed in Table 4, the vessels included in this thesis could not be representative for all categories, since none of the participating vessels could be distributed into category I respective category V. Therefore, it was necessary to estimate data for category I and V (section 3.3).

To estimate how the environmental loads of copper differ depending on the copper dosage, two scenarios were executed in MAMPEC BW, one where the dosing according to the concentration given by the ICAF system manufacturers (section 2.3) and the other based on a median value calculated from the laboratory analysis result (Figure 15).

Case study II

Location: OECD EU Commercial harbour

Scenario 1. MAMPEC AF

Antifouling paint

Based on the average amount of vessels in the harbour

Vessels

Cat I	Cat II	Cat III	Cat IV	Cat V
11	5	5	1	2

Antifouling paint leach rate:

2.5 $\mu\text{g}/\text{cm}^3/24\text{h}$

Scenario 2. MAMPEC BW

Median concentration

Cu conc. And SW flow based on estimations in Table 4

Copper concentration in discharged seawater

0.0427 mg/l

Total discharge of seawater (Ballast water in MAMPEC)

40176 $\text{m}^3/24\text{h}$

Scenario 3. MAMPEC BW

Manufacturers' concentration

SW flow based on estimations in Table 4

Copper concentration in discharged seawater

0.002 mg/l

Total discharge of seawater (Ballast water in MAMPEC)

40176 $\text{m}^3/24\text{h}$

Figure 15. MAMPEC Case study II, scenario 1-3 particulars

3.4 Calculations of annual copper release

The sample is only representative for the anodes in the sea chest in use at the time of the sampling. The actual seawater flow during sampling is also highly relevant for the sample since the concentration will vary greatly depending on the flow. Many vessels today possess the ability to adjust the flow of seawater depending on the current cooling needs (section 2.1.1.1).

It was therefore decided to calculate the theoretical load of copper that is released in total, including the “inactive” sea chest(s). Since the electrolysis process in the inactive sea chests still is active even though the seawater system uses another sea chest, there are emissions of copper to the seawater that cannot be traced with the help of the sample taken, as illustrated in Figure 8, section 2.3.

3.4.1 Anode loss of mass between service intervals

Another approach used to estimate the amount of copper released from the anodes per year, was to take the number, volume, and density of the anodes and compare to the exchange period. The length and diameter, for calculating the volume of the anode, as well as the total numbers of anodes, was provided for the calculations by the questionnaire (*APPENDIX III*). The density of copper was calculated with the value 8 926 kg/m³.

A factor concerning the wear of the anodes at the time replaced was accounted for, since it is unlikely that the anode would be completely consumed at the time of the replacement, as this would adventure the antifouling efficiency, as described in section 2.3. To find out how much of the anodes that were left during replacement, an experienced Chief Engineer was contacted, and he stated that normally, 85-90% of the anode was used. This correlates quite well with the value given by one manufacturer (Section 2.3). It was therefore decided to calculate with a factor of 0,90, implying that 90% of the original copper (Cu) mass in the anode was released to the sea (Equation 2).

Equation 2. Released copper per year

V	m ³	Anode Volume
D	m	Anode Diameter
L	m	Anode Length
n		Number of anodes
m	kg	Mass
T	years	Change of anodes interval
ρ	kg/m ³	Density

$$V_{Total} = \left(\pi \frac{D}{2} 2^2 \right) * L * n$$

$$m_{Total} = V_{Total} * \rho_{Cu}$$

$$\left[\frac{kg}{year} \right] = \frac{m_{Total} * 0,85}{T_{[years]}}$$

3.4.2 Calculation of copper emissions based on chemical analysis versus manufacturers' recommendations

To display the copper emissions caused by the ICAF system during a year, the concentration given by the sample analysis and the seawater flow given by the questionnaire (Table 3) was used (Equation 3). The same formulas were then used with the same seawater flow, but with the manufacturers' stated copper concentration of 2 µg/l (section 2.3), to compare these values with the values given by the laboratory analysis. There are 8765,81 hours on a year (if calendar leap years are included), therefore this value was used in the calculation to demonstrate the released copper during a year, since the MGPS is in constant operation to prevent fouling.

As described in section 3.4, these values were only representative for the actual sea chest and sea water system in use at the time of the sample taking. These values were therefore not representative for the whole vessels accumulated release of copper into the sea. Also, the calculations were based on that the copper concentration given by both the sample analysis and the manufacturers was constant and not changed between service intervals. The seawater flow had to be assumed constant during the year as well.

However, since vessel D provided two samples from two different seawater systems, it was presented in the calculations as D₁ respectively D₂. D₁ was sampled from an inactive sea chest, and D₂ was sampled from the sea chest in use.

Equation 3. Copper emissions based on analysis and manufacturers' recommendations

ρ_i	kg/m ³	Mass Concentration
\dot{m}	m ³ /h	Mass Flow
T	h	Running hours per year

$$\rho_i \left[\frac{kg}{m^3} \right] = \rho_i \left[\frac{\mu g}{L} \right] * 10^{-6}$$

$$\left[\frac{kg}{year} \right] = T * \rho_{iCu} * \dot{m}_{seawater}$$

3.4.3 Copper emissions on a global scale

Since ICAF is such a common system around the globe, a scoping calculation was made to provide insight on the scale of copper emissions worldwide this causes. Cathelco states that about 50 000 vessels worldwide are equipped with their ICAF system (section 2.3). The total number of vessels equipped with ICAF systems is most likely greater than that concerning that this amount does not include other manufacturers, such as Cathwell. However, it does not appear which size and type of vessels that are included in this number (for example, smaller yachts which in this context accounts for a limited amount of emissions), and no other data on the occurrence of ICAF systems was found. It was therefore decided to assume that 50 000 vessels worldwide use ICAF systems in the calculations.

A mean seawater flow, based on the average flow from all vessels participating in this study was used together with a copper concentration of 2 µg/l (section 2.3) to calculate the yearly respectively daily copper emissions. A median value on the sampled copper concentration was calculated from the sample analyses, which allowed for a comparison between the emissions at ideal conditions and actual conditions. It is necessary to clarify that this estimation only includes the copper emitted by the active sea water cooling system, and not the copper released in other sea chests (Figure 8).

3.5 Economic aspects

Apart from environmental aspects, there are also economic aspects to consider. To get a perspective on the eventual economical savings that could be made, the price of the anodes was calculated into a price per kilo/anode to be able to state a price difference. However, amounts concerning the exchange, transport and scrapping of the anodes has not been accounted for.

The price of the anodes was received from Cathwell (Table 2). Since the price per kilo differed by the anodes' size (the larger the anode, the lower was the price per kg) a mean price per kg was calculated. Each anodes mass was calculated using the formulas in section 3.4.1. By calculating the price of the total mass of copper released annually, both for the values given in Table 6 and Table 7, a comparison can be made and an estimation on how much that could be saved by adjusting the dosage rate to 2 µg/l for the actual seawater flow.

4 RESULTS

The copper concentration in the discharged seawater (Figure 16) was significantly higher than the stated 2 $\mu\text{g/l}$ given from the manufacturers, with a median value of 42,7 $\mu\text{g/l}$. The average concentrations from all samples were 93,1 $\mu\text{g/l}$, however, this value was greatly affected by the highest concentration sampled, which was 413 $\mu\text{g/l}$. The average zinc value was 81,0 $\mu\text{g/l}$ and the median 59,6 $\mu\text{g/l}$.

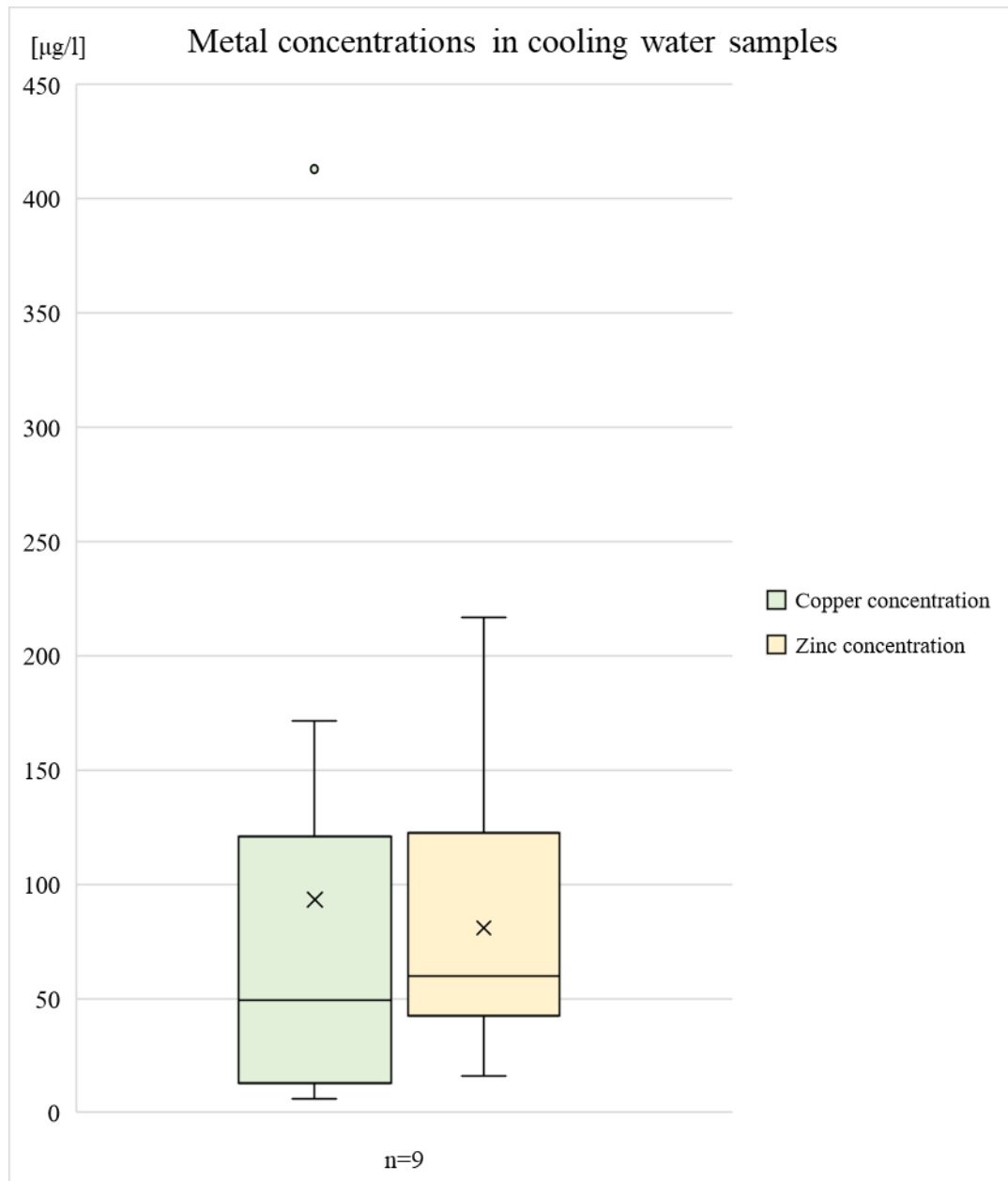


Figure 16. The average levels of copper and zinc in the ICAF-treated seawater. The average value is displayed as the "x" and the median value is represented by the horizontal line within the box.

4.1 Estimated load of copper from ICAF systems compared to other sources of copper to the marine environment in a type port

The case studies performed in MAMPEC demonstrated that the load from ICAF treatment compared to antifouling paints varied depending on the vessels; When only vessels in this study were accounted for, the copper load from the ICAF system was close to two times larger, but when using the average number and sizes of vessels in a type port, the load from the ICAF was lower and corresponded to 74% of the load from antifouling paints (Figure 17). The results are only representative for the active sea chest at the time of the sampling. The copper amounts in the sediment after ten years caused by ICAF was about 0,4 µg/g dry weight, slightly lower than from the antifouling paint (Figure 19 and Figure 20). The moving vessels in the port were not accounted for, leading to that the results are a slight underestimation of the actual environmental load.

4.1.1 ICAF versus antifouling paint (Case study I)

There was a significant difference between the estimated environmental concentrations of copper in the sea caused by ICAF when the manufacturers' concentration of 2 µg/l respective the median sampled concentration of 42,7 µg/l were used in the scenarios, as demonstrated by Figure 17. The average Predicted Environmental Concentration (PEC) calculated by MAMPEC for the sampled values was 0,048 µg/l, and the average PEC for the manufacturer's' value was 0,0042 µg/l. This can be compared with the average PEC of 0,026 µg/l that was caused by the antifouling paint. The copper load from the ICAF system was nearly twice as high (182%) compared to the antifouling paint. These values are based on that all nine vessels in the study are located in the same OECD harbour at the same time, to allow for a comparison between ICAF respective antifouling emissions in a standardized European harbour.

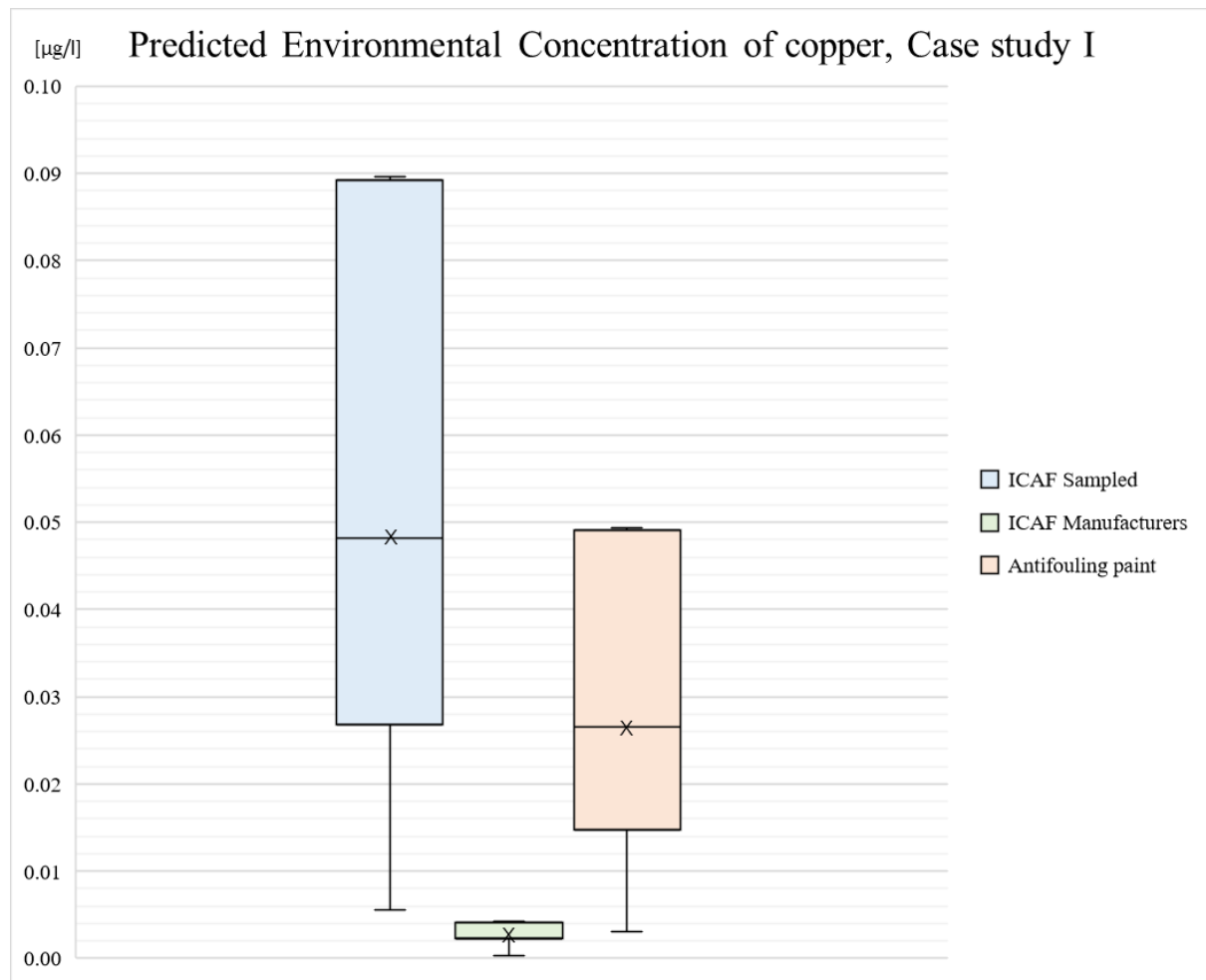


Figure 17. Copper emissions from ICAF and antifouling paints

4.1.2 ICAF and antifouling paint comparison in a type port (Case study II)

MAMPEC was used to simulate the actual copper load, from both ICAF systems and the antifouling coating, in a realistic harbour scenario. The results differed from the first case study. When using the sampled median concentration in the scenario, the copper load from the ICAF system was lower compared to the copper load from antifouling coating (Figure 18). The size of the load from the ICAF system (sampled) was 74% of the load caused by the antifouling paint. However, if the ICAF copper concentration would have been the stated 2 µg/l, the load from the ICAF system would only be about 3,5 % compared to the antifouling paint load. The average concentration from ICAF (sampled) was 0,032 µg/l, respective 0,0023 µg/l (manufacturers concentration), and the average concentration from antifouling paints was 0,027 µg/l.

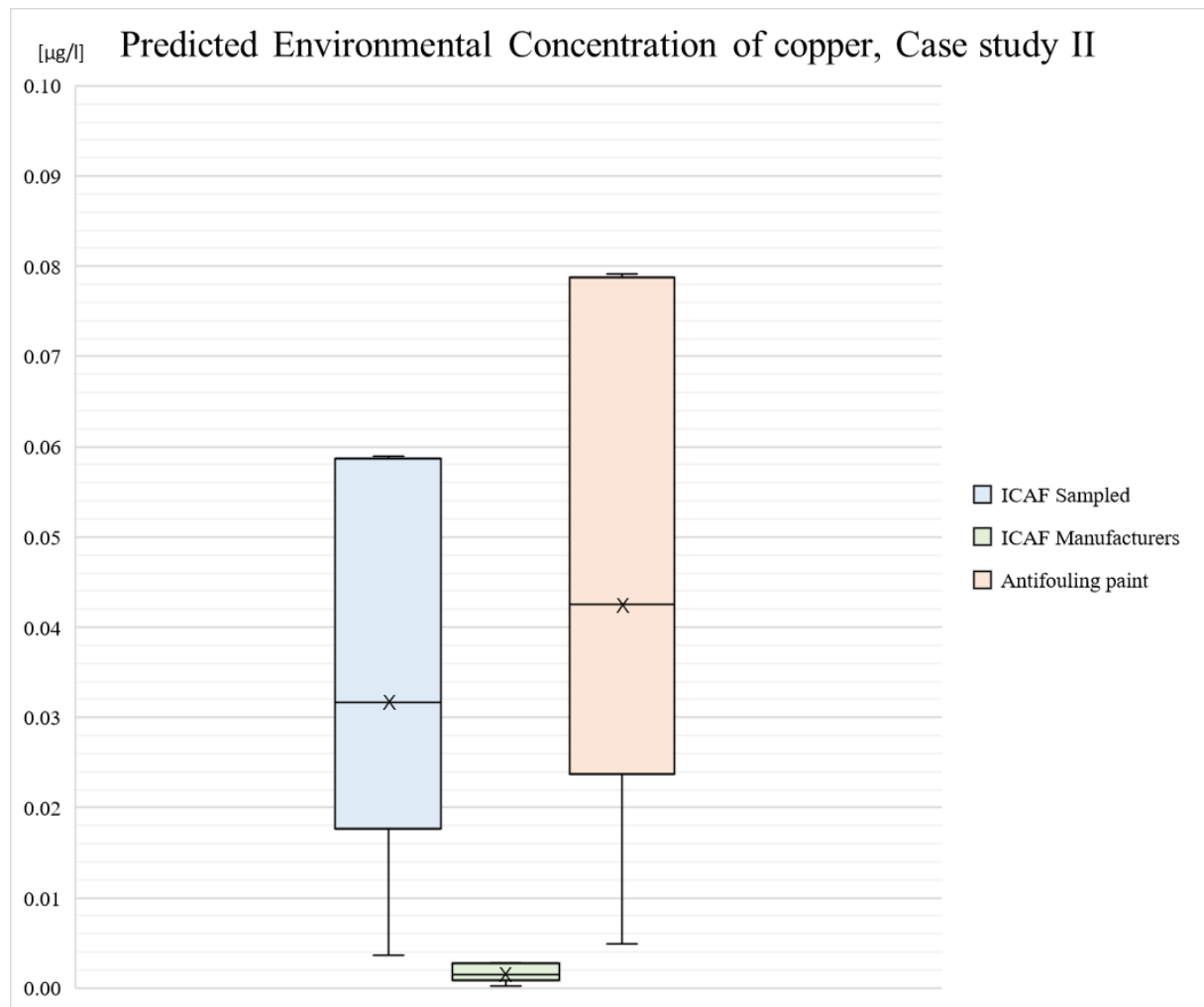


Figure 18. Copper loads from ICAF compared to antifouling paint

Case study II provided the estimated copper in the sediment after 1, 2, 5 and 10 years caused by ICAF, for both the ideal (Figure 19-a) and sampled (Figure 19-b) copper concentration released from the ICAF system. The PNEC value of copper in the sediment is 52 µg/g dw (section 2.6). The maximum level of copper in the sediment after 10 years was 0,019 µg/g dw when the concentration of copper in the discharged cooling water was tuned for 2 µg/l. When the median sampled value of 42,7 µg/l, was used, the maximum copper concentration in the sediment was 0,407 µg/g dw after 10 years. In comparison, the maximum copper amount in the sediment origin from the antifouling paint was 0,546 µg/g dw (Figure 20).

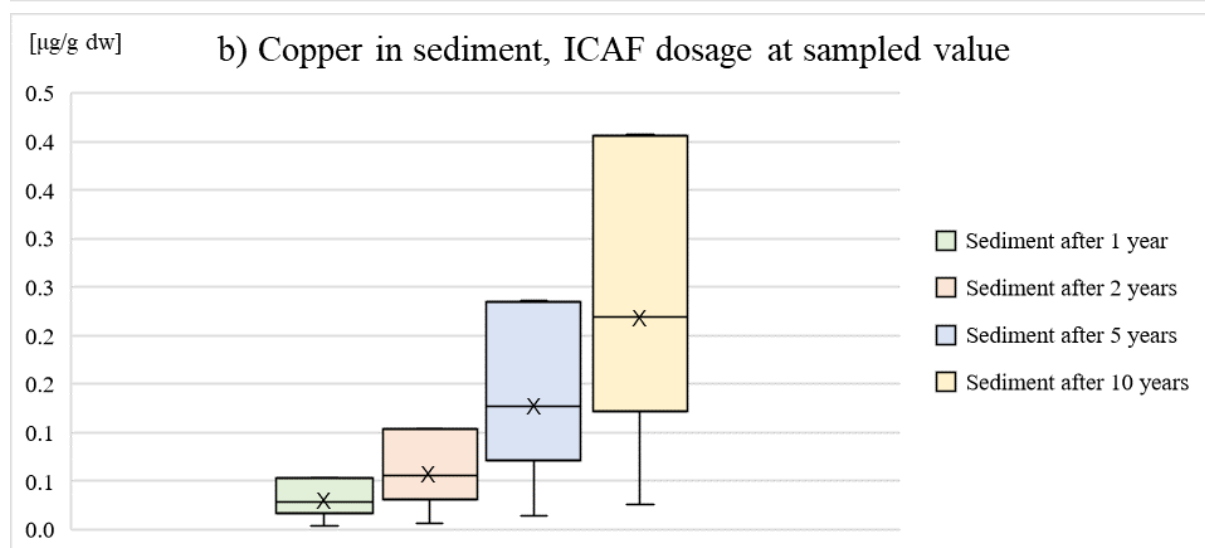
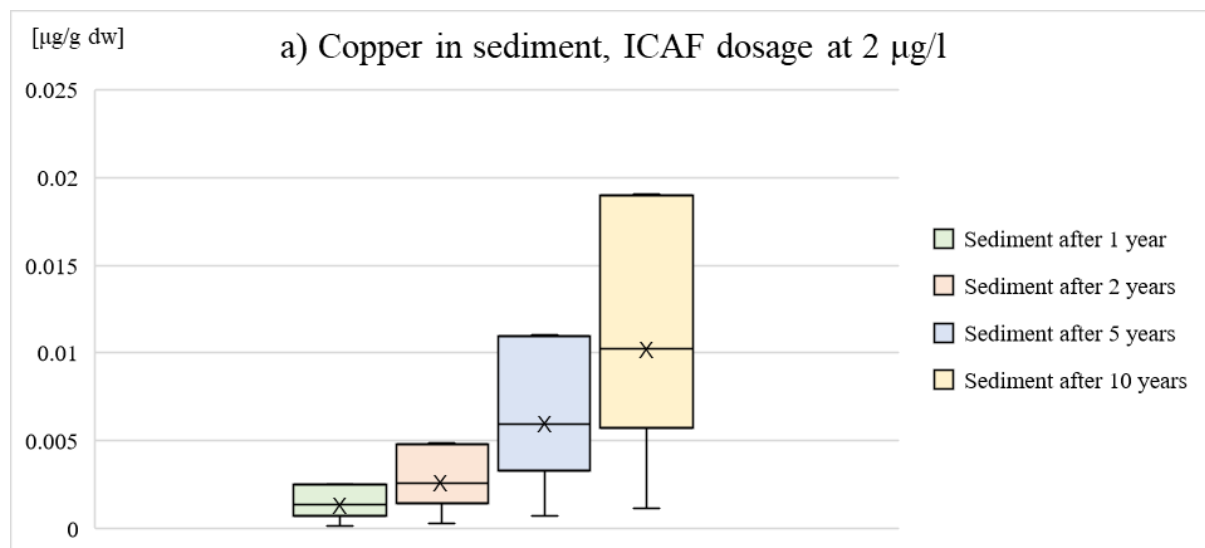


Figure 19. PEC of copper in sediment from ICAF, MAMPEC Case study II

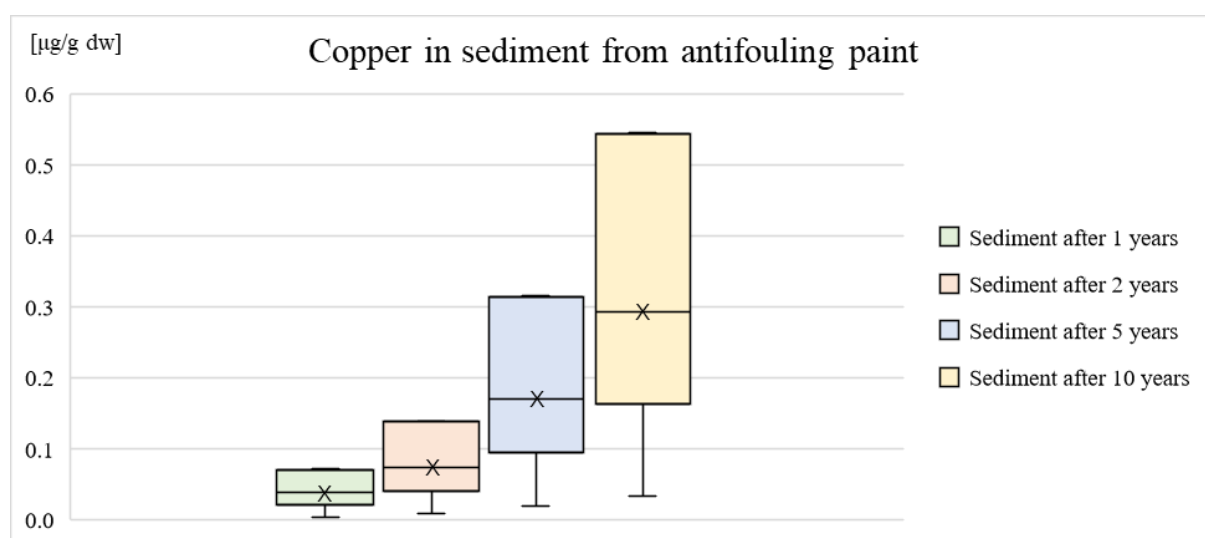


Figure 20. PEC of copper in sediment from antifouling paint, MAMPEC Case study II

4.2 Calculated annual copper emissions

The yearly emissions of copper from each vessel were nearly 70 kg in average, when all the anodes on the vessels were accounted for. The majority of the vessels exchanged the anodes after 2-3 years (Figure 21), and nearly 90% had anodes mounted in the sea chest. The calculated emissions based on the sample analysis and the seawater flow revealed that the copper emissions per year would be close to 50 times larger on average than the theoretical emission based on that the copper concentration would be at the manufacturers' stated value.

4.2.1 Copper emissions based on exchange interval

The total mass of anodes differed significantly from vessel to vessel. 89% of the vessels included in this study had anodes mounted in the sea chest, and 11% had the anodes mounted in strainer boxes, according to the questionnaire. The calculated annually copper emissions, when taking all anodes onboard into consideration, differed notably, from 15 kg to 100 kg per vessel. Even when each vessels engine power was accounted for, the interval from lowest to highest copper emissions were significant, ranging from 1,4 to 9.6 kg copper per year/MW (Table 5).

Table 5. Copper released based on change interval

Vessels	Total volume anodes [l]	Total mass [kg]	Used until replacement [kg]	Change interval [years]	Released Cu [kg/year]	Released Cu [kg/Year/MW]
Vessel A	20	183	164	2,5	66	2,9
Vessel B	37	332	299	3	100	2,4
Vessel C	20	183	164	2	82	3,6
Vessel D	29	259	233	2,5	93	9,6
Vessel E	58	515	463	5	93	3,0
Vessel F	5	41	36	2,5	15	2,3
Vessel G	23	202	182	2	91	5,7
Vessel H	14	128	115	2,5	46	1,8
Vessel I	17	154	138	3	46	1,4
Average	25	222	200	2,8	70	3,6
Median	20	183	164	2,5	82	2,9

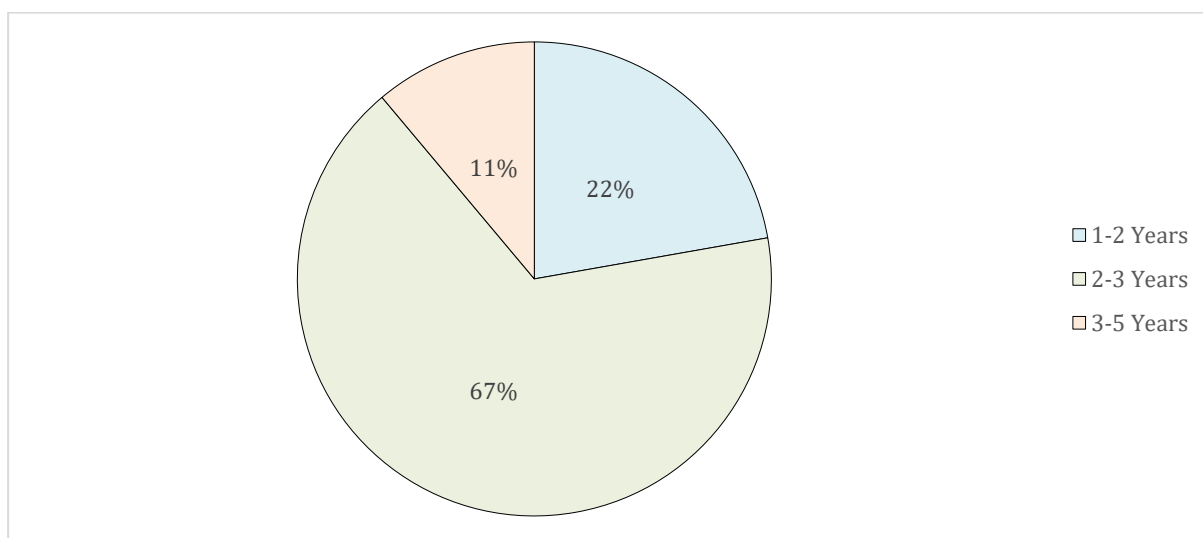


Figure 21. Distribution of anode exchange interval between vessels

4.2.2 Calculated copper emissions based on sample analysis

The copper concentrations in the sampled cooling water onboard the vessels varied greatly, ranging from 5,90 to 413 µg per litre seawater (Table 6). Consideration to seawater flow to provide an annual copper emission overview, further increased the range (5 to 919 kg copper per year) and did not correlate to the estimated copper emissions per year presented in 4.2 (Table 5). The calculations are assuming that the concentration is constant (section 3.4.2) with no adjustment of current, which was the case for 89% of the vessels in this study (Figure 22). The results were based only on the active parts of the seawater system and anodes at the sampling time (Table 6).

Table 6. Based on data from onboard sampling

Vessels	Cu conc. [µg/l]	Seawater flow [m ³ /h]	Cu emitted [kg/year]	Cu emitted, based on change intervals [kg/year]
Vessel A	14,1	160	20	66
Vessel B	5,90	180	9	100
Vessel C	10,2	160	14	82
Vessel D ₁	104	6	5	93
Vessel D ₂	56,1	50	25	93
Vessel E	42,7	400	150	93
Vessel F	33,4	50	15	15
Vessel G	80,7	1300	919	91
Vessel H	413	160	579	46
Vessel I	172	90	135	46
Average	93,1	256	187	70
Median	42,7	160	23	82

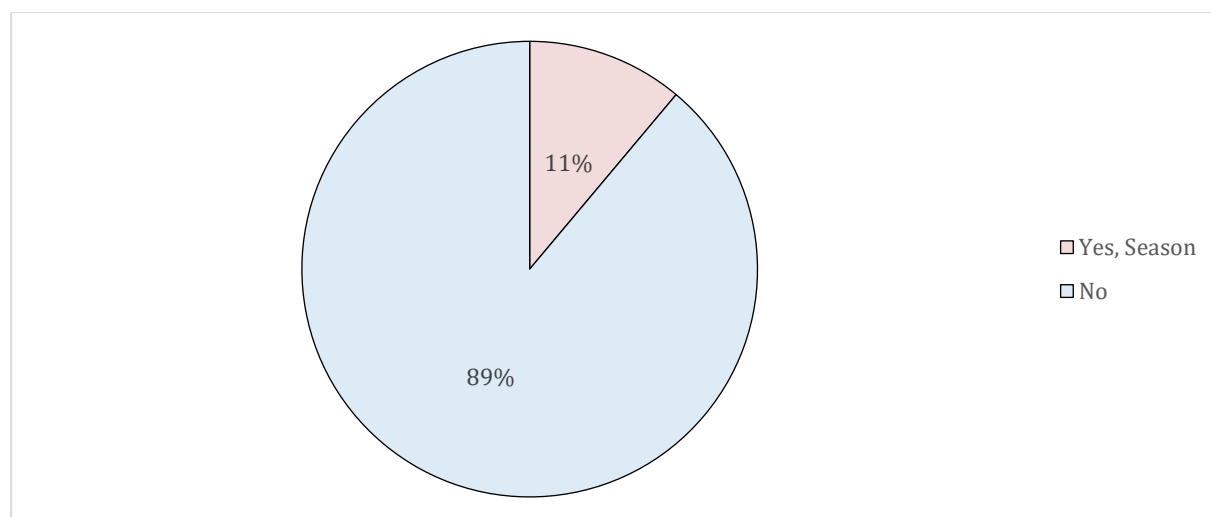


Figure 22. Active adjustment of current on the ICAF system. None of the vessels actively adjusted according to location

4.2.3 Calculated copper emissions based on manufacturers' statements

When the copper concentrations were based on 2 µg/l instead of the results from the onboard sampling, the estimated annual copper emissions were significantly lower, ranging from 1- 23 kg copper per year (Table 7) instead of 5-919 kg copper per year (Table 6). As in Table 6, the results presented in Table 7 only account for the active parts of the seawater system and the anodes fitted there, with the exception of vessel D (section 3.4.2). The emissions of copper per year differed drastically between the sampled concentration calculations and the calculations based on the concentration stated by the manufacturers. The concentrations obtained from onboard sampling led to copper emissions nearly 47 times greater on average.

Table 7. Emissions according to the manufacturers' stated value

Vessels	Cu level [µg/l]	Flow [m³/h]	[kg/year]	Difference to sample results [%]
Vessel A	2	160	3	703
Vessel B	2	180	3	295
Vessel C	2	160	3	510
Vessel D ₁	2	6	0,1	5200
Vessel D ₂	2	50	1	2805
Vessel E	2	400	7	2133
Vessel F	2	50	1	1668
Vessel G	2	1300	23	4033
Vessel H	2	160	3	20650
Vessel I	2	90	2	8575
Average	2	256	4,5	4657
Median	2	160	3	2469

4.2.4 Estimated copper emissions on a global scale

Table 8 displays the daily respective yearly release of copper to the sea, calculated with the estimation that 50 000 vessels are using this system. If all the vessels operated with a copper dosage at 2 µg/l, there would be a significant amount (384 kg/day) of copper emitted, which would lead to that 140 tonnes of copper per year would have been released.

If the copper dosage worldwide would be set to the median value of the sample analysis concentration, over three tonnes copper per day would have been emitted, leading to 1 229 tonnes per year, an amount of emissions nearly ten times higher. Copper emissions from inactive sea chests has not been accounted for.

Table 8. Global copper emissions

Description	Cu concentration median [µg/l]	Average flow [m³/h]	Cu emitted [kg/day]	Cu emitted [ton/year]
According to Manufacturers	2	253	384	140
Sample analysis	42,7	253	3366	1229

4.3 Economic factors

The calculations resulted in large variations; therefore, the median value is presented instead of the average, which would be misleading due to the extremely high values from vessel G and H. The median difference between the estimated cost at the recommended copper concentration of 2 µg/l respective the sampled concentration was 685 €. The expected economic benefit per year, of reducing the flow to 2 µg/l varied significantly from vessel to vessel, from 178 € to nearly 26 000 € (Table 9).

Table 9. Economical comparison

Vessels	Annual Cu consumption, actual conc. [kg/year]	Annual Cu consumption, 2 µg Cu/L [kg/year]	Annual cost, actual concentration	Annual cost, 2 µg Cu/l	Difference
Vessel A	20	3	569 €	81 €	488 €
Vessel B	9	3	269 €	91 €	178 €
Vessel C	14	3	413 €	81 €	332 €
Vessel D	25	1	711 €	25 €	685 €
Vessel E	150	7	4 321 €	203 €	4 119 €
Vessel F	15	1	422 €	25 €	397 €
Vessel G	919	23	26 557 €	659 €	25 899 €
Vessel H	579	3	16 738 €	81 €	16 657 €
Vessel I	135	2	3 910 €	46 €	3 864 €
Median	25	3	711 €	81 €	685 €

5 DISCUSSION

The concentrations of copper in the sampled cooling water were significantly higher than the manufacturers statement, with a median concentration of 42,7 $\mu\text{g/l}$ instead of the 2 $\mu\text{g/l}$ concentration estimated by the manufacturers. The concentrations differed significantly between the vessels; the highest concentration of copper in the ICAF-treated seawater was 413 $\mu\text{g/l}$, to be compared with the lowest value of 5,9 $\mu\text{g/l}$. The variation of concentrations caused the average concentration to be notably high, 93,1 $\mu\text{g/l}$, which was the reason for the use of the median value in most calculations and modellings (Figure 16).

According to the scenarios done in MAMPEC, the copper emissions caused by the ICAF system was about three quarters of the copper amount emitted from antifouling paints, and this is only with the sampled part of the seawater system. Since most vessels are equipped with at least two, but often even more sea chests, each with anodes to prevent fouling in respective sea chest, the copper load is with high probability at least twice as high.

As described in section 1.1.2, the copper emissions caused by shipping in the Baltic sea exceeds the total amount of copper released from Sweden, and these estimations did not consider ICAF systems. This means that the copper emitted from ships are greatly underestimated, since the only emission source of copper accounted for today is the antifouling coating.

5.1 Environmental load modeling and case studies in MAMPEC

As pictured in Figure 17, the proportion of copper emissions caused from ICAF versus antifouling paint varies greatly depending on the concentration of copper in the sea cooling water. If the ICAF system is operating according to the manufacturers' instruction of 2 $\mu\text{g/l}$ copper, the maximum copper load caused by ICAF represented less than 10% of the maximum load that the antifouling paints contribute to, according to both case studies (9% in Case study I respective 3,5 % in Case study II). However, when the simulation was based on the median concentration presented by the laboratory analysis (42,7 $\mu\text{g/l}$), the maximum load of copper caused by the ICAF system corresponded to 74% of the antifouling paint in Case study II. This was the most realistic setup since it accounted for different sizes of vessels, based on data from European harbours. Considering that the loads above only included the active sea chest, total environment loads are most probably higher than these MAMPEC simulations presented. Since most vessels have at least two sea chests (section 2.1), the actual copper emissions could be more than twice as high, leading to a load notably greater than the antifouling paint. It should be stated that the vessels moving in the port according to the predefined emission compound OECD EU Commercial harbour were neglected due to practical reasons, and that real world emissions would be slightly higher than the results presented in this thesis.

The case studies performed in MAMPEC demonstrated that the copper load from ICAF treatment compared to the load from antifouling paint varied, from twice as high compared to antifouling paint load in Case study I, to where the ICAF treatment load was about three quarters of the antifouling paint load in Case study II. There may be several reasons for this, but the main reason is that ferries normally have a relatively high engine power for its size compared to merchant vessels such as tankers or other cargo vessels, which can be noticed from the vessel particulars in this study (Table 3). Higher engine power leads to higher cooling demands, leading to a higher seawater flow and therefore the necessity for a higher copper consumption. Since seven out of nine vessels in this study was RoPax ferries, the copper load comparison from ICAF treatment and antifouling paint on vessels, respectively, in this thesis

(Case study I) will lead to that the ICAF treatment represents a greater part of the load than when other vessel types and categories is included (Case study II).

Since the estimations made to allow for environment load modelling comes with some uncertainty linked to the underlying assumptions and simplifications, caution shall be taken when analysing the result; however, the arrangement is suitable for making relative comparisons. One factor which adds to the uncertainty was the limited number of vessels participating in the study. The copper concentration and seawater flow from vessels in Category I and V therefore had to be estimated based on existing data, to be able to match the pre-set number of vessels in an average port according to MAMPEC. The estimations were based on the world fleet average engine power for tankers at different sizes (section 3.3). It was decided to use the values for tankers since they generally have less engine power relative to their size than RoPax vessels, therefore providing a broader spectrum of the simulation. Another limiting factor was that MAMPEC only performs 2D-modelling, and therefore cannot include all real-world parameters. However, these estimations enable assessment of relative importance of copper emissions from anti-fouling paint versus ICAF.

Concerning the PEC copper levels in the sediment caused by ICAF, the concentration after ten years with the copper dosing of 2 µg/l was about 0,02 µg/g dry weight, according to Case study II. When the copper dosing was based on the sampled values, this PEC value was reached already after one year (Figure 19). The copper levels in the sediment after 10 years with the ICAF sampled copper dosage was about 0,41 µg/g dry weight, over 20 times higher. However, it is still not reaching the PNEC value of 52 µg/g dry weight, even if the value would be multiplied twice to account for inactive sea chest(s). The PNEC values were not reached even when the PEC from both ICAF and the antifouling paint was combined.

5.2 Total copper emissions caused by ICAF

As described in section 3.4, the results from the sample taking itself do not represent all the copper emissions caused by ICAF systems. Therefore, the total amount of anodes, together with the exchange interval, were used to calculate an estimated value on the amount of copper released to the sea per year. As revealed by this study, the exchange period for the anodes was normally 2-3 years (Figure 21), with some exceptions. The exchange of anodes typically takes place during dry-dock (section 2.3), which is a costly and complex procedure, and is often planned together with other major overhauls or service jobs, according to authors' experience. This leads to that the exact service period of the anode can vary from time to time, since it depends on several other factors.

The expected annual release of copper per vessel in this study ranged from approximately 70-80 kg per year, depending on if the average or median value was used. This can be compared with the expected annual emissions based on the sample which ranged from 23 kg (median) to 187 kg (average). According to calculations demonstrated by Table 5 and Table 6, some of the vessels copper emission per year exceeds the total amount of copper in the anodes onboard, which of course is impossible. These high values can be traced to different sources; the fact that the calculations had to assume that the seawater flow and copper concentration were constant during a year (section 3.4.2), and to eventual contamination of the samples.

However, if only the median values are considered, the copper emissions calculated from the sample analysis would be around 25% of the total copper emissions calculated from the total amount of anodes onboard. This is a reasonable value, considering that the sample analysis-based calculation only accounts for the active sea chest, and most vessels have at least two sea

chests or more (section 2.1). According to the authors' experience, RoPax vessels generally have multiple main engines, two or more, and therefore a more complex seawater cooling system. This leads to that they usually have more sea chests than vessels with only one main engine. It would therefore not be unreasonable to assume that the anodes are distributed in several different sea chests, and that the calculated concentrations correspond well to real world concentrations.

5.3 Global emissions discussion

The seawater flow used in this calculation is, as stated, an average on the flow given by the vessels that participated in this study. However, due to the relatively small number of vessels included, combined with the relatively narrow geographical area, leads to the fact that the average flow used for the calculations not necessarily is an accurate representation of the global fleet.

The calculation only demonstrates the copper release caused by the active part of the sea water system, meaning that emissions from sea chest(s) currently not in use is neglected (Table 8). The actual copper emissions are with great probability significantly higher. Concerning that most vessels have at least two sea chests, the copper emitted would be twice as high, about 2400 tonnes per year instead of circa 1200 tonnes per year. That would be about three times higher than the total emissions of copper released into the Baltic sea in 2011, and over ten times the amount of copper released from Sweden in 2006 (section 1.1.2), and this only from the vessels' ICAF systems.

If all vessels equipped with ICAF treatment would have a dosing system, which would adjust the copper dosage according to the seawater flow, the amount of copper released into the oceans could be reduced significantly. If it is assumed that the copper concentrations and seawater flow retrieved from this study is relatively representative for the world fleet, over 2 000 tonnes of copper could have been saved.

5.4 How does the load of copper from ICAF systems compare to available EQS?

As displayed in Figure 18, with an average emitted copper load of 0,032 µg/l from the seawater based on the sample, it is still within PNEC limits. Even if the maximum PEC was used (0,059 µg/l), no PNEC values was reached. However, when inactive sea chests were accounted for, the PEC was significantly higher than the PEC from leaching copper caused by the antifouling coating, regarding both the seawater concentration and in the sediment (Table 10). The estimated PEC of copper with an additional sea chest is demonstrated in parentheses.

Table 10. Comparison PNEC and PEC from MAMPEC Case study II

Copper in sediment, [µg/g dry weight]				PEC of copper, [µg/l]			
PNEC, coastal and transition zone waters	PEC after 10 years ICAF (Sampled)	PEC after 10 years, anti-fouling paint	PEC after 10 years, ICAF and antifouling paint combined	PNEC, Baltic sea	Max. PEC of Cu from ICAF (sampled)	Max. PEC of Cu from anti-fouling paint	Max. PEC of Cu from ICAF and Anti-fouling combined
52	0,546 (1,092)	0,407	0,953 (1,499)	1,45	0,059 (0,118)	0,079	0,138 (0,197)

5.5 The seawater temperature's effect on the cooling system and copper dosage adjustment

Of course, the cooling efficacy of the seawater are directly correlated to the temperature, which means that the required flow of seawater to achieve a certain cooling effect depends on the time of the year. According to the authors' experience, frequency-controlling of seawater pumps are becoming more and more common since it allows the flow to be adjusted depending on cooling needs. A direct result of the flow variations is that the copper emission concentration will be higher than needed during the colder time of the year, when the cooling needs are lower (section 2.3). As displayed in Figure 22, a total of 11% of the vessels stated that they actively adjusted the current (and therefore, the release of copper) according to season. None of the vessels in this study actively adjusted the current depending on the location.

The adjusting of current based on location is connected to how large area the vessel normally trades in; Vessels with a narrow trading area or vessels on a certain route, for example ferries, may not have the need to adjust the current depending on the location. This because they trade in the same area most of the time, with small changes in seawater salinity, fouling species et cetera. However, adjustment of the current based on season (and indirectly, seawater temperature) ought to be easier for these vessels since they can predict the season variations more precise than vessels trading worldwide.

As demonstrated in the results, the copper concentrations in the ICAF-treated seawater are high for almost all vessels. Adjusting the current would benefit the vessels and companies' economy, as well as the ecosystem and its reproduction. The fouling pressure from blue mussels is most significant during the mussels' reproduction phase, which begins around 10-12°C (section 2.4.2), which in Swedish waters occur from the beginning of May to June (Figure 9). With this knowledge, the copper dose could potentially be increased manually to prevent the mussel larvae from settling, and then be adjusted to a lower value during other times of the year when the reproduction does not occur. However, if the copper dosage is increased too much during reproduction, it may also have the side effect that it affects the natural reproduction in the marine environment. Lowering the dosage during the year when the biofouling species' reproduction does not occur could be beneficial from both economic and environmental perspectives.

5.6 Estimated anode lifetime

As described in section 2.3, the ICAF system is usually tuned to keep the copper concentration around 2 µg/l at maximum seawater flow. However, many vessels normally operate with significantly lower flows, or adjusts the flow according to cooling needs (section 2.1.1). According to a Chief Engineer on one of the vessels included in the study, the seawater flow was normally at about 30% of maximum capacity. To estimate the difference in expected lifetime of the anode depending on the flow, two numbers were calculated: The expected anode life with the flow stated during sample taking, and the expected anode life at maximum flow (Equation 4). In the cases where the maximum flow was uncertain, the flow during sample taking was multiplied with a factor of 3,33 (Assuming that the seawater flow was around 30 % at the time of sampling). The total mass of copper anodes was retrieved from previous calculations (section 3.4.1). The concentration of 2 µg/l, given by the manufacturers, was used. All seawater flows had to be assumed constant over the year in the calculations.

Equation 4. Estimated anode lifetime

ρ_i	kg/m ³	Mass concentration
\dot{m}_{actual}	m ³ /h	Seawater flow, actual
\dot{m}_{max}	m ³ /h	Seawater flow, maximum
m	kg	Mass
T_{actual}	years	Expected anode lifetime at actual flow
T_{max}	years	Expected anode lifetime at max. flow

$$T_{actual} = \frac{m_{Cu}}{\rho_{iCu} * \dot{m}_{actual} * 8765,81}$$

$$T_{max} = \frac{m_{Cu}}{\rho_{iCu} * \dot{m}_{max} * 8765,81}$$

Demonstrated in Table 11 are the calculated lifetime of the anodes, with a copper dosage of 2 µg/l. As displayed, the lifetime of the anode would be greatly increased when the copper dosage was tuned for the actual flow instead of the maximum flow. The average calculated life of the anodes was 2,2 years, to be compared with the average of 10 years if the copper dosage would have been based on the flow at the time of the sampling. However, an interesting fact was that the calculation (Table 11) confirmed that the anodes were dimensioned for the maximum flow rate, since the expected anode life at maximum seawater flow correlated relatively well with the exchange interval of the anodes, apart from some exceptions.

Table 11. Estimated anode lifetime

Vessels	Cu level [µg/l]	Flow during sampling [m ³ /h]	Maximum flow [m ³ /h]	Expected anode life, sampling flow [years]	Expected anode life, maximum flow [years]	Exchange interval [years]
Vessel A	2	160	533	7	2,2	2,5
Vessel B	2	180	600	12	3,5	3,0
Vessel C	2	160	533	7	2,2	2,0
Vessel D	2	50	700	33	2,4	2,5
Vessel E	2	400	1333	8	2,5	5,0
Vessel F	2	50	167	5	1,6	2,5
Vessel G	2	1300	1800	1	0,7	2,0
Vessel H	2	135	450	6	1,8	2,5
Vessel I	2	90	300	11	3,3	3,0
Average		281	713	10	2,2	2,8

5.7 The economical factor

As can be seen by Table 9, there is an economical benefit on reducing the dosage of copper as well. However, since the calculated sums are based on the values from the sample analysis and the assumption that the seawater flow during sampling would be constant during the year, the copper concentration and seawater flow greatly affects the calculated costs. This is clearly demonstrated by vessel G and H, who would be able to save about 17 000 respectively 26 000 € if they adjusted the copper dosage to 2 µg/l for the actual flow (Table 9). These sums are, even when vessel size and engine power is accounted for, unreasonably high. Most of the vessels studied have similar or greater engine power and are comparable in size (Table 3).

Despite this, Table 9 demonstrates that there are in fact potential to cut expenses by adjusting the concentration to actual flow used during normal conditions rather than the maximum flow that rarely occurs, except for vessels trading in tropical waters. However, neither of the vessels included in this study stated that they had such systems onboard. This should be of interest and a benefit to the ship owners. Maybe, the installing of a flow-regulating copper dosage system will be feasible. According to Cathwell, their ICAF systems are already prepared for flow

regulation, and only needs to be complemented with a cable and a sensor to set the copper dosage according to the flow (P. Kittilsen, personal communications, April 13th, 2021).

However, an aspect of lowering the copper concentration that is not investigated in this thesis is how the antifouling properties are affected by the lower copper concentrations. As described in section 1.1.3, there are indications that a copper dosage of 2 µg/l is not entirely effective in preventing biofouling (Grandison et al., 2011; Growcott et al., 2017). According to Saidov *et al.* (2019), a concentration of 4-10,8 µg/l is required to kill half the population of blue mussels. Concerning barnacles, a concentration of 145 µg/l is required to kill half the population (Qiu et al., 2005). Fouling in sea chests and the seawater system can lead to additional expenses, not only for the vessel and shipowner in the form of extra maintenance and wear, but also for the local society, in the form of a higher risk of the spreading of NIS (section 1.1.1). It is therefore necessary to study the efficacy of ICAF systems at a deeper level.

5.8 Method and procedure discussion

This thesis was based on three main methods:

- Literature analyses on topics regarding the subject and background theory
- Conducting a seawater sample onboard relevant vessels for analysing, including instructions and a questionnaire
- Simulations made in MAMPEC for comparison between different scenarios and loads from sea cooling water contra antifouling paint

The sample kits sent out to the vessels contained bottles of 0,5-1 l (depending on batch). However, the amount that ALS laboratory needed to analyse the sampled water was only 25 ml. The decision to send larger bottles to the vessels, and then pouring over the sample into the 25 ml bottles before sending the samples to the laboratory, was made for several reasons. Easier handling for the crew was one aspect. Another aspect was the fact that the quantity of seawater received from the vessels allowed for a second analysis, which were done to increase the reliability of the samples. Even if the sample analysis would be unusable for some reason (for instance, lost in transport, damaged/missing labels on the bottles, leakage, or other causes), there was still enough sampled water to send another batch. Every step regarding the sample adds to the uncertainty, however, the advantages were considered to outweigh the eventual disadvantages, and efforts were made to minimise the risk of sample error sources, such as the use of plastic gloves and the shaking of the sample to make it completely homogenous before pouring it over to the smaller bottle.

The samples were sent to the laboratory in two batches, where batch one was divided into two shipments, since the total number of samples was not known at the time for the first shipment. It was decided to ship existing samples and then send another shipment when additional samples had been retrieved. When all samples received in total had been analysed, it was decided to perform a second analysis to get better sample reliability. The samples were not refrigerated during the transport; however, the sampling process was executed during late winter and spring, with low temperatures outside, and the samples were immediately stored in a refrigerator upon arrival. The results of all three laboratory analyses (batch 1a, 1b, and 2) are attached in *APPENDIX IV*. When referring to the manufacturers' statement of the copper concentration in this thesis, 2 µg/l was used for calculations, simulations et cetera. This is because both Cathelco and Cathwell states this on their websites. No other manufacturers of ICAF systems were accounted for in this study.

5.8.1 Sample analysis discussion

It is essential to consider all potential impacts on the chemical analysis results. The placement of anodes in the sea chest made the analysing of a “before”-sample from a scientific view unavailable. This due to the difficulty of taking the sample and the numerous error sources that would be difficult to trace and explain. Vessels equipped only with strainer-mounted anodes allow for a sample taking before the treatment and therefore, a comparison between the untreated and the treated seawater would have been possible. However, no before-samples were retrieved from vessels with strainer-mounted anodes only, which complicates the ability to draw conclusions from the analysis results.

It is always desirable to strive for having the same person to perform the sampling, to minimize the variations related to the sample taking. However, this was not possible in this study, due to the ongoing Covid-19 pandemic, which contributes to the uncertainty in the results. Sampling onboard vessel G was made in another type of containers, clean bunker (fuel) sample bottles. However, since the bunker sample bottles are used for bunker analysing, and therefore needs to be very clean, the risk of the sample being contaminated due to the bottles was considered unlikely.

Co-author Sjöström had the opportunity to carry out the sampling on one of the vessels (section 3.2.1). This visit resulted in a deeper understanding and knowledge of how the seawater treatment worked onboard. When the sample was taken, the author used the instructions they had written themselves (*APPENDIX II*). This gave the author a confirmation of how well the instructions were written. The sample was taken after the seawater/LT-water cooler through a drain valve.

When the sampling was executed, the authors' understanding regarding why there is no possibility of taking samples before the electrolysis treatment, before the anodes, were confirmed. This was because the anodes in the vessel were mounted directly in the sea chest. With this knowledge, it was possible to understand what it would mean to arbitrarily sample outside the vessel, in example before the electrolysis treatment. In theory, it would work to lower a bucket outside the hull to bring up seawater, but that would have required access to cleaned buckets to ensure that the bucket had not been used for another purpose in an earlier state and contain substances that may affect the test result. There are also practical obstacles; at sea, the vessels speed makes it difficult to take the sample. When the vessel is at berth, it would be possible to take a sample. However, the port itself may contain higher concentrations of copper or other substances that may affect the analysis result. As mentioned in section 1.1.1, the vessel's hull is treated with an antifouling paint that contains and releases copper to prevent growth. This release also occurs when the vessel is at berth, which could contaminate the bucket, leading to a higher copper content in the sample than it should have. This means that the test result would therefore not reliable.

In an optimal world, a smaller boat would have been needed, which has an untreated hull. This would then allow going out to the place where the sample (after the sea chest) was taken and then use a disinfected bucket, alternatively a sampling bottle to take a reliable sample which had then been a sample before the sea chest. As is understandable, these alternatives are not practically possible to implement in the study. However, the vessels had the opportunity to take the samples outside the hull, but this only to give the authors an opportunity to compare and gain an understanding of the copper content.

5.8.2 Design of the questionnaire

The questionnaire attached with the sampling kit was a part of the puzzle to get a good overview of the different vessels and their particulars. However, a more structured and detailed questionnaire could have provided a better understanding. Questions regarding the antifouling paint used on the vessel could provide an insight on the fact that the antifouling paint, especially if based on copper, could have an impact on the heavy metal levels of the discharged seawater.

Additional information regarding the sampling, concerning engine load, seawater flow and vessel condition could also provide for a better clarity when analysing the results. According to the authors' understanding, more and more ships are equipped with frequency-controlled pumps, which allows the flow to be adjusted depending on engine load and other conditions. The vessel conditions, for instance if the vessel is at anchorage, berthed or at sea during the sample taking, is also relevant since the exchange of water around the sea chest varies. It is therefore reasonable to believe that the impact from the copper released from antifouling paints differs as well. A study with more focus on the questionnaire could picture a broader perspective on the result of the analysis.

5.8.3 Aspects that can affect the copper levels

Since the main antifouling paints used in the shipping industry, especially on the vessels' hulls, are based on emitting copper to prevent fouling (Finnie & Williams, 2010), the copper levels in the treated seawater can be affected by the copper emitted from the paint. Without the "before treatment"-sample, there is no certain way to determine from which source the copper emissions origins. Another aspect that can affect the level of copper is the location of the sample point. Some vessels have copper de-aeration pipes. Since the concentrations are in the size of parts per billion, it might have biased the measured copper concentrations.

As displayed in Figure 16, the zinc concentration from the analyses is quite high relative to the copper concentrations. In the authors' experience, there are often zinc anodes mounted in the heat exchangers and on the vessels. These are not connected to the ICAF system and only acts as sacrificial anodes to prevent corrosion.

6 CONCLUSION

The results demonstrate that when calculating the copper emissions from ships, the sea cooling water and its treatment systems cannot be neglected. To investigate the complete copper emissions caused by MGPS on vessels, beside from the active sea chest and sea water system, inactive sea chest(s) needs to be accounted for.

- Most vessels have the ICAF system tuned for the maximum capacity of seawater flow, leading to a high concentration of copper when operating with lower seawater flows.
- Adjusting the copper concentration to the actual seawater flow could reduce the environmental impact and additionally, be an economical benefit for the shipowners.
- The copper load caused by ICAF differed, corresponding from 74-182% of the antifouling paint load. However, when accounting for inactive sea chest(s), the load from ICAF would be at least twice as high.
- The proportion between environmental loads from ICAF and antifouling paints depends on the vessel particulars; Vessels with high engine power relative to their size, such as RoPax ferries, will have a higher proportion of the copper load from ICAF compared to vessels with lower engine power relative to their size, such as tankers.
- No PNEC-limits given by the EQS from the Swedish Agency for Marine and Water Management were reached by the load from ICAF treatment, even if inactive sea chests were accounted for.

6.1 Recommendations for further research

Further studies on a deeper level are necessary to fully understand the scale and consequences that the copper emitted from this system accounts for. As discussed in this thesis, the sample from the seawater cooling system cannot provide a complete view of the copper emissions related to the ICAF system. An alternative approach that could provide more accurate determinations of the amount of copper emitted, would be to investigate the remains of the anodes in detail, such as weighing the replaced anodes and compare with a new one. An exact date on the service life of the anodes would also be required. This would allow for a study without any sampling necessary, and ships equipped with box water coolers could also be included.

A study involving analysing and sampling of ICAF-treated seawater with respect to metal speciation, is necessary to better evaluate the emission and reaction (and indirectly toxicity) of copper in the cooling water. This can also facilitate understanding of the copper origin in the seawater; if it is caused by the ICAF treatment itself, or other factors such as the antifouling paint affects the sample. However, metal speciation analyses would have to be executed immediately after the sample taking, preferably onboard the vessel, and the samples cannot be stored for later analysis.

As mentioned in section 1.4, this thesis focuses only on Scandinavian and North European waters, and vessels that have connection to Sweden. For further studies, it would be interesting to investigate how many vessels that uses ICAF systems worldwide. As described in section 2.3, more than 50 000 vessels around the globe are using this type of system, and this is only from one manufacturer, Cathelco.

6.1.1 Box water cooling systems and ICAF

A solution that, according to the authors understanding, is becoming more and more common, especially in the small to medium tanker vessel segment, is to use box water cooling. Box water cooling systems requires a MGPS to prevent growth on the heat exchanger, which would impact the heat exchange efficiency on the box cooler, as described in section 2.3. Due to the practical issues, vessels with box water cooling have been excluded (section 1.4). However, a more detailed study on the concentrations of copper released from sea chests equipped with ICAF system is needed to plot the difference between metallic emissions from box water cooled vessels compared to vessels equipped with a conventional sea water cooling system.

6.1.2 Efficiency of ICAF systems at 2 µg/l

As displayed in Table 6, all the vessels included in this thesis had copper concentrations significantly greater than 2 µg/l. This study does not go into detail on how the efficacy of ICAF systems varies with different copper dosage in the seawater and that is a factor that needs further investigation.

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APPENDIX I - OTHER MGPS ALTERNATIVES

To provide the interested reader an additional understanding of some of the other MGPS, a description of the technical operation and properties of these systems is provided below. The figures are listed at the Table of figures of the main thesis.

CHLORINE MGPS

A widespread chemical treatment for biofouling, both in the shipping industry and in shore-based facilities such as industries and power plants are by using chlorine as a biocide. Its chemistry, toxicity and ecotoxicity effects are well studied and it is relatively cheap. There are three major ways to achieve chlorination of the seawater, by chlorine gas, solid tablets like granular dichloride, and by adding sodium hypochlorite either as a liquid or by electro-chlorination on place (Grandison et al., 2011; Growcott et al., 2017; Rubio et al., 2015).

The chemistry of chlorination in seawater is very complex. This is due to the large number of reactions with organic respective inorganic substances that takes place. This will lead to that not all the chlorine can be used as a biocide. However, certain reactions result in the forming of bromine, which is even more effective as a biocide than chlorine. However, discharged seawater that contain chlorine residuals can have a negative impact on the marine ecosystem. (Growcott et al., 2017).

The efficacy of chlorine based MGPS depends on several factors, such as temperature, pH and which biofouling species that are targeted. Several mussel species, including *M. edulis*, closed their shells when they were exposed to chlorine. To overcome this, either the exposure period has to be prolonged, or the concentration of chlorine have to be increased (Growcott et al., 2017). However, this may cause other issues as the chlorination can lead to increased corrosion of the pipework if overdosed. It is therefore important to carefully monitor the dosage rate to avoid corrosion (Grandison et al., 2011). Chlorination can also be combined with copper electrolysis (Rubio et al., 2015).

OSMOTIC SHOCK MGPS

The principle behind osmotic shock is based on a sudden change of the solute concentration of salinity around a cell, which will cause a rapid change in the movement of water across the cell membrane. When an organism adapted to live in seawater with high salinity is exposed to freshwater, water enters the cells, and by that cause the cells to swell and either (cell lysis) or undergo apoptosis. This procedure can be seen in Figure 23. The figure shows two different solvents with different salinity levels, separated by a semipermeable membrane, for instance cell membrane. Water will flow through the membrane, but the salt molecules will not be able to pass, therefore leading to that organisms used to live in a higher salinity will die through cell lysis. For freshwater organisms, the mechanism is opposite and they will shrink due to dehydration if exposed to water of higher salinity (Nelson, 2017).

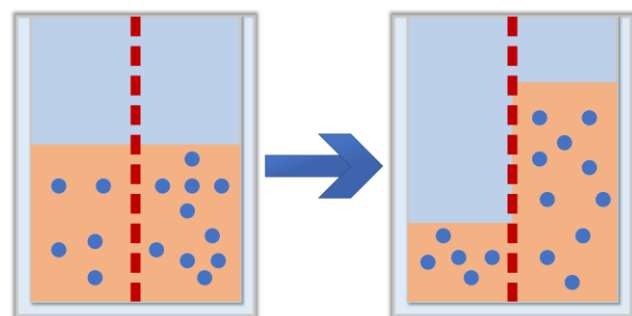


Figure 23. Salt particles (blue dots) will not pass the membrane (red line), but water will pass through. Left side of red line is inside the cell (Nelson, 2017)

To use this principle as an antifouling treatment on vessels, freshwater or technical water is induced in the sea chest. This will induce mortality in the biofouling species that are used to full oceanic salinity (35‰) and prevent new growth.

Growcott et al. (2017) states that this process may take up to 14 days to achieve 100% mortality. They also state that if the turnaround time is less than 4 days, it will cause significant delays and associated economic costs. Further, the osmotic shock can also cause some new organisms to spawn, which will negatively affect the ecosystem. Another aspect is that the consumption of freshwater may be cost-prohibitive and generate a poor perception within community within locations/times of low rainfall and water restriction implementation. Some of the organisms could tolerate freshwater for up to 38 days, which will reduce the overall efficiency of osmotic shock treatment (Grandison et al., 2011).

THERMAL TREATMENT BASED MGPS

The addition of heat in niche areas, for example by inducing steam in sea chests, is an environmentally friendly and cheap antifouling method. Experiments have shown that steam application cause complete mortality for several biofouling species (Growcott et al., 2017; Joyce et al., 2019).

Two different methods for achieving a thermal shock are mentioned in Growcott et al. (2017). One is by recirculating the seawater, increasing the water temperature, and thus creating a thermal shock. This type of temperature rise can cause cell and ultimately organisms' death through the denaturing of proteins. However, due to the vessel's operation area, different species, organisms, size of the organisms, different temperature, time of the treatment for the organisms to disappear must be observed. In some cases, the water needs to be above 42° C in at least two hours to maintain 100% mortality. The thermal shock can also contribute to new species being introduced into new seawater areas, negatively affecting the ecosystem (Growcott et al., 2017).

Another aspect that must also be observed is the difficult in heat distribution in the sea chests using the seawater's recirculation method. Results show that the tolerance of organisms in sea chest should be observed with caution, as the structure of biofouling collection may provide thermal protection areas for some organisms. Sublethal temperature exposure could cause new organisms to spawn (Growcott et al., 2017).

The second method of achieving thermal shock is by using steam. This method has considerably more advantages than heating the seawater by recirculation. When using steam as a thermal shock, the seawater must first be evacuated from the area to be treated (Growcott et al., 2017). The steam, which is produced onboard, can then be used to clean the sea chests in dry dock or in water operation (Joyce et al., 2019). The advantages of steam are, inter alia, that it provides a quick treatment and needs less energy than recirculated seawater, and by using steam, the whole sea chest and seawater pipe system does not need to be heated. Another aspect with steam is the coating inside the sea chest, the temperature of the steel needs to maintain below 65° C (Growcott et al., 2017).

However, the thermal treatment of seawater is not that common. Grandison et al. (2011) concluded that the treatment method, regarding thermal treatment, needs to be investigated more since inducing a thermal shock requires the temperature to increase rapidly and maintain the right temperature for a certain time to avoid any acclimatization of new organisms.

ULTRASONIC BASED MGPS

By creating an electrical discharge, an acoustic energy pulse is generated, which travels through pipe walls and creates small gas bubbles that implode (cavitates). This induces an electro-hydraulic shock to the biofouling organisms which kills them (Grandison et al., 2011).

The system consists of a power supply and several transducers which emits the ultrasonic frequencies. The transducers can either be mounted in sea chests or at the hull, depending on which biofouling that the MGPS should suppress. The installation is inside the vessel, which means that no dry-docking is needed for installation or maintenance (Cathwell, n.d.-b; Ultraguard Antifouling, n.d.).

Since this treatment do not depend on the release of toxic substances or biocides, the ultrasonic MGPS by itself is not harmful for the marine environment. (Grandison et al., 2011) However, the efficacy of ultrasonic energy as a MGPS for niche areas needs further examination to fully understand the environmental consequences. If the biofouling prevention is insufficient, that would lead to both economical and operational consequences along with environmental consequences caused by the spread of NIMS (Bell & Kluza, 2011; Coutts & Dodgshun, 2007; Growcott et al., 2017). Cathwell, which is a major manufacturer of various MGPS systems, states that the technology is not efficient enough to protect sea chests from biofouling alone, but should be installed together with another type of MGPS such as the ICAF system. The reason for this is the complexity of marine biofouling (Cathwell, n.d.-b).

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APPENDIX II - INSTRUCTIONS



CHALMERS






Instructions for Sea water Cooling Sample

You have received a total of two bottles. These bottles are marked with **AFTER ELECTROLYSIS TREATMENT** and **BEFORE ELECTROLYSIS TREATMENT**.


If the anodes are mounted on a strainer, use the **“before electrolysis treatment”**-bottle and take a sample before the anodes (if possible). Otherwise, skip this step and use only the **“after electrolysis treatment”**-bottle.

The sample should be taken at the sea water cooler recently in use. (For example, during filter cleaning). If there is no possibility to take the sample at the cooler, please add a note on where the sample has been taken. It is Important that the sample is taken after the seawater electrolysis (Cathelco) treatment.

Taking the Sample:

-  Use the gloves provided to minimize the risk of the sample getting contaminated.
-  Flush the sample bottle with seawater from the sea water cooler.
-  Fill the sample bottle with seawater from the sea water cooler.
-  Seal the containers and fill in the details on the attached form.
-  Repack the samples and the filled form paper in the box and send it. The data and results will not be able to be traced back to the ship.

Delivery

-  When the sample kit is ready to be sent, please attach the following freight note and send.

Thank You for Your Cooperation!

Yours Sincerely,

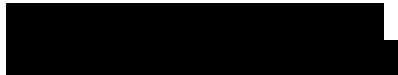
Jonatan Alexanderson

André Sjöström

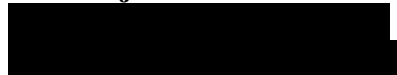
Contact

If you have any questions or concerns regarding the sample or form, please do not hesitate to contact us:

Jonatan Alexanderson



André Sjöström



APPENDIX III - QUESTIONNAIRE



CHALMERS

Investigation of machinery space due to thesis at *Marine Engineering programme, Chalmers University*

Complementing information for the test results. These questions are relevant for us to create a picture of the machinery space. Some of the questions may not have a direct answer but we want you to answer approximately.

This form is containing questions for the seawater test.

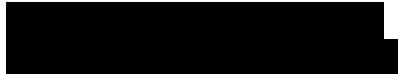
This form will take 10-15 minutes to fill in.

The answers may be used in the report if it's relevant for the conclusion, however name of the ship or information that may reveal your ship will be excluded.

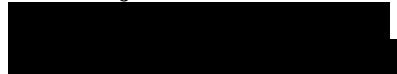
We hope that you will find this interesting and are willing to answer as thoroughly as possible.

Yours Sincerely,

Jonatan Alexanderson



André Sjöström



Marine Engineering BsC Thesis course

Chalmers University of Technology

1. Name of the ship

Answer: _____

2. Sea-area of the ship when the test result was taken?

Answer: _____

3. Time (UTC) and date

Answer: _____

4. What type of propulsion system do you use? (Diesel-electric, shaft with reduction gear box etc)

Answer: _____

5. Main Engine(s), Model and Make:

Answer: _____

6. Number of Main Engine(s)

☐ 1

☐ 2

☐ 3

☐ 4

☐ 5

7. Running hours (main engine)

Answer: _____

8. Fuel for the main engine

- ☐ HFO
- ☐ ULSFO (Ultra-Low-Sulphur-Fuel Oil)
- ☐ Diesel
- ☐ LNG
- ☐ Other _____

9. Auxiliary Engines, Model and Make:

Answer: _____

10. Number of auxiliary engines

- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6

11. Running hours for auxiliary engines

Answer: _____

12. Do you use scrubber?

- ☐ Yes
- ☐ No

13. How high is the current (A) used in the electrolysis system?

Answer: _____

14. Do you adjust the current, depending on season or location?

- ☐ Yes, season
- ☐ Yes, location
- ☐ No

15. If yes (At the previous question), when and why do you do that?

Answer: _____

16. What is the flow of the seawater (m³/h) where the sample is taken?

Answer: _____

17. If flow determination is not possible, what are the diameter of the main seawater pipes? (Average)

Answer: _____

18. What is the pressure of the seawater at the sample test location?

Answer: _____

19. What type of material are the pipes for the seawater?

- ☐ Steel Pipe
- ☐ Cupro-nickel
- ☐ Other _____

20. What type of anodes do you have (several answers can be necessary)?

- ☐ Copper anodes
- ☐ Aluminium anodes
- ☐ Ferrous anodes
- ☐ Other _____

21. Where are the cathodes and anodes located?

- ☐ Sea chest
- ☐ Strainer box mounted on the sea water piping
- ☐ Other _____

22. How many, and what size (length & diameter) of the Copper anodes do you have?

Answer: _____

23. How many and what size (length & diameter) of the other (Ferrous/Aluminium) anodes do you have?

Answer: _____

24. How often are the anodes exchanged?

Answer: _____

25. When was the last time the anodes were replaced?

Answer: _____

26. Other Notes

APPENDIX IV - ALS ANALYSIS RESULT

SAMPLE BATCH 1a)



Analyscertifikat

Ordernummer	: LE2101398	Sida	: 1 av 12
Kund	: Chalmers Tekniska Högskola	Projekt	: Länsvatten
Kontaktperson	: Ida-Maja Hassellöv	Beställningsnummer	: 303032, 30IDHAS1
Adress	: Hörselgången 4	Provtagare	: ---
	: 412 96 Göteborg	Provtagningspunkt	: ---
	: Sverige	Ankomstdatum, prover	: 2021-03-10 13:33
E-post	: ida-maja@chalmers.se	Analys påbörjad	: 2021-03-11
Telefon	: ---	Utfärdad	: 2021-03-17 13:51
C-O-C-nummer	: ---	Antal ankomna prover	: 19
(eller			
Orderblankett-num			
mer)			
Offertnummer	: ST2021SE-CHA-TEK0001 (OF210027)	Antal analyserade prover	: 19

Generell kommentar

Denna rapport får endast återges i sin helhet, om inte utfärdande laboratorium i förväg skriftligen godkänt annat. Laboratoriet tar inget ansvar för information i denna rapport som har lämnats av kunden, eller resultat som kan ha påverkats av sådan information. Beträffande laboratoriets ansvar i samband med uppdrag, se vår webbplats www.alsglobal.se

Signatur	Position
Ilia Rodushkin	Laboratoriechef



Laboratorium	: ALS Scandinavia AB	hemsida	: www.alsglobal.com
Adress	: Aurorum 10	E-post	: info.lu@alsglobal.com
	: 977 75 Luleå	Telefon	: +46 920 28 99 00
	: Sverige		

Sida : 2 av 12
 Ordernummer : LE2101398
 Kund : Chalmers Tekniska Högskola



Analysresultat

Matris: VATTEN		Provbeteckning		ID. 101			
		Laboratoriets provnummer		LE2101398-001			
		Provtagningsdatum /tid		2021-02-22			
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Al, aluminium	4.02	± 5.45	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	0.800	± 0.140	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	18.6	± 1.9	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	135	± 14	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	<0.05	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	14.8	± 1.5	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0165	± 0.0017	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	119	± 12	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	350	± 35	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	1.36	± 0.52	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	2.45	± 0.44	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	3080	± 308	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	1.58	± 0.34	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	0.368	± 0.087	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	0.390	± 0.051	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	32.6	± 3.4	µg/L	2.0	V-3a	W-SFMS-5D	LE

Matris: VATTEN		Provbeteckning		ID. 102			
		Laboratoriets provnummer		LE2101398-002			
		Provtagningsdatum /tid		2021-02-22			
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Al, aluminium	2.20	± 5.44	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.01	± 0.15	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	19.1	± 1.9	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	136	± 14	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	<0.05	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	5.67	± 0.60	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0118	± 0.0012	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	122	± 12	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	358	± 36	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	1.60	± 0.53	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	2.68	± 0.45	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	3160	± 316	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	0.693	± 0.310	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	<0.2	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	0.564	± 0.065	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	66.5	± 6.7	µg/L	2.0	V-3a	W-SFMS-5D	LE

Sida : 3 av 12
 Ordernummer : LE2101398
 Kund : Chalmers Tekniska Högskola



Matris: VATTEN		Provbeteckning	ID. 103					
		Laboratoriets provnummer	LE2101398-003					
		Provtagningsdatum /tid	2021-02-22					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.	
Al, aluminium	2.26	± 5.44	µg/L	2.0	V-3a	W-SFMS-5D	LE	
As, arsenik	1.01	± 0.15	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Ba, barium	18.4	± 1.9	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Ca, kalcium	121	± 12	mg/L	0.2	V-3a	W-AES-1B	LE	
Cd, kadmium	<0.05	----	µg/L	0.05	V-3a	W-SFMS-5D	LE	
Co, kobolt	<0.05	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Cr, krom	<0.5	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Cu, koppar	10.6	± 1.1	µg/L	1.0	V-3a	W-SFMS-5D	LE	
Fe, järn	0.0170	± 0.0017	mg/L	0.00400	V-3a	W-SFMS-5D	LE	
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE	
K, kalium	105	± 11	mg/L	0.5	V-3a	W-AES-1B	LE	
Mg, magnesium	307	± 31	mg/L	0.09	V-3a	W-AES-1B	LE	
Mn, mangan	1.07	± 0.51	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Mo, molybden	1.92	± 0.41	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Na, natrium	2700	± 270	mg/L	0.2	V-3a	W-AES-1B	LE	
Ni, nickel	0.689	± 0.310	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Pb, bly	<0.2	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
V, vanadin	0.296	± 0.044	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Zn, zink	16.8	± 1.9	µg/L	2.0	V-3a	W-SFMS-5D	LE	

Matris: VATTEN		Provbeteckning	ID. 104					
		Laboratoriets provnummer	LE2101398-004					
		Provtagningsdatum /tid	2021-02-22					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.	
Al, aluminium	37.7	± 6.6	µg/L	2.0	V-3a	W-SFMS-5D	LE	
As, arsenik	0.921	± 0.147	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Ba, barium	16.2	± 1.6	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Ca, kalcium	185	± 19	mg/L	0.2	V-3a	W-AES-1B	LE	
Cd, kadmium	<0.05	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Co, kobolt	<0.05	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Cr, krom	<0.5	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Cu, koppar	102	± 10	µg/L	1.0	V-3a	W-SFMS-5D	LE	
Fe, järn	0.149	± 0.015	mg/L	0.00400	V-3a	W-SFMS-5D	LE	
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE	
K, kalium	175	± 18	mg/L	0.5	V-3a	W-AES-1B	LE	
Mg, magnesium	519	± 52	mg/L	0.09	V-3a	W-AES-1B	LE	
Mn, mangan	3.79	± 0.63	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Mo, molybden	3.90	± 0.53	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Na, natrium	4610	± 461	mg/L	0.2	V-3a	W-AES-1B	LE	
Ni, nickel	2.60	± 0.40	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Pb, bly	3.20	± 0.33	µg/L	0.20	V-3a	W-SFMS-5D	LE	
V, vanadin	0.426	± 0.054	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Zn, zink	215	± 22	µg/L	2.0	V-3a	W-SFMS-5D	LE	

Sida : 4 av 12
 Ordernummer : LE2101398
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Matris: VATTEN		Provbeteckning	ID. 105					
		Laboratoriets provnummer	LE2101398-005					
		Provtagningsdatum /tid	2021-02-22					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.	
Al, aluminium	111	± 12	µg/L	2.0	V-3a	W-SFMS-5D	LE	
As, arsenik	1.12	± 0.16	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Ba, barium	16.4	± 1.6	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Ca, kalcium	184	± 18	mg/L	0.2	V-3a	W-AES-1B	LE	
Cd, kadmium	<0.05	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Co, kobolt	<0.05	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Cr, krom	<0.5	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Cu, koppar	55.7	± 5.6	µg/L	1.0	V-3a	W-SFMS-5D	LE	
Fe, järn	0.0367	± 0.0037	mg/L	0.00400	V-3a	W-SFMS-5D	LE	
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE	
K, kalium	174	± 17	mg/L	0.5	V-3a	W-AES-1B	LE	
Mg, magnesium	515	± 52	mg/L	0.09	V-3a	W-AES-1B	LE	
Mn, mangan	3.23	± 0.60	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Mo, molybden	4.01	± 0.54	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Na, natrium	4560	± 456	mg/L	0.2	V-3a	W-AES-1B	LE	
Ni, nickel	2.96	± 0.42	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Pb, bly	0.492	± 0.093	µg/L	0.20	V-3a	W-SFMS-5D	LE	
V, vanadin	0.486	± 0.059	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Zn, zink	54.6	± 5.5	µg/L	2.0	V-3a	W-SFMS-5D	LE	

Matris: VATTEN		Provbeteckning	ID. 106					
		Laboratoriets provnummer	LE2101398-006					
		Provtagningsdatum /tid	2021-02-22					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.	
Al, aluminium	36.0	± 6.5	µg/L	2.0	V-3a	W-SFMS-5D	LE	
As, arsenik	<0.5	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Ba, barium	9.85	± 0.99	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Ca, kalcium	23.0	± 2.3	mg/L	0.2	V-3a	W-AES-1B	LE	
Cd, kadmium	<0.05	----	µg/L	0.05	V-3a	W-SFMS-5D	LE	
Co, kobolt	0.0669	± 0.0986	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Cr, krom	<0.5	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Cu, koppar	8.00	± 0.82	µg/L	1.0	V-3a	W-SFMS-5D	LE	
Fe, järn	0.0429	± 0.0043	mg/L	0.00400	V-3a	W-SFMS-5D	LE	
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE	
K, kalium	5.06	± 0.51	mg/L	0.5	V-3a	W-AES-1B	LE	
Mg, magnesium	11.6	± 1.2	mg/L	0.09	V-3a	W-AES-1B	LE	
Mn, mangan	7.63	± 0.91	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Mo, molybden	0.995	± 0.375	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Na, natrium	79.0	± 7.9	mg/L	0.2	V-3a	W-AES-1B	LE	
Ni, nickel	2.50	± 0.39	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Pb, bly	<0.2	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
V, vanadin	0.408	± 0.053	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Zn, zink	13.4	± 1.6	µg/L	2.0	V-3a	W-SFMS-5D	LE	

Sida : 5 av 12
 Ordernummer : LE2101398
 Kund : Chalmers Tekniska Högskola



Matris: VATTEN		Provbeteckning	ID. 107				
		Laboratoriets provnummer	LE2101398-007				
		Provtagningsdatum /tid	2021-02-22				
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Al, aluminium	51.6	± 7.5	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	0.587	± 0.129	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	9.08	± 0.92	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	35.5	± 3.6	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05	----	µg/L	0.05	V-3a	W-SFMS-5D	LE
Co, kobolt	0.0622	± 0.0986	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	42.3	± 4.2	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.246	± 0.025	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	18.3	± 1.8	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	50.8	± 5.1	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	12.6	± 1.4	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	0.942	± 0.374	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	427	± 43	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	3.47	± 0.46	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	1.96	± 0.21	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	0.291	± 0.044	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	110	± 11	µg/L	2.0	V-3a	W-SFMS-5D	LE

Metodsammanfattningar

Analysmetoder	Metod
W-AES-02	Analys av metaller i förorenat vatten med ICP-AES enligt SS-EN ISO 11885:2009 och US EPA Metod 200.7:1994 efter uppslutning av prov enligt W-PV-AC.
W-AES-1B	Analys av metaller i förorenat vatten med ICP-AES enligt SS-EN ISO 11885:2009 och US EPA Method 200.7:1994. Analys utan föregående uppslutning. Provet är surgjort med 1 ml HNO ₃ (suprapur) per 100 ml före analys. Detta gäller ej prov som varit surgjort vid ankomst till laboratoriet.
W-AFS-17V3a	Analys av kvicksilver (Hg) i förorenat vatten med AFS enligt SS-EN ISO 17852:2008. Analys utan föregående uppslutning. Provet är surgjort med 1 ml HNO ₃ (suprapur) per 100 ml före analys.
W-AFS-17V3b	Analys av kvicksilver (Hg) i förorenat vatten med AFS enligt SS-EN ISO 17852:2008 efter uppslutning av prov enligt W-PV-AC.
W-PV-AC	Upplösning med salpetersyra i autoklav enligt SS 28150:1993 (SE-SOP-0400).
W-SFMS-06	Analys av metaller i förorenat vatten med ICP-SFMS enligt SS-EN ISO 17294-2:2016 och US EPA Metod 200.8:1994 efter uppslutning av prov enligt W-PV-AC.
W-SFMS-5D	Analys av metaller i förorenat vatten med ICP-SFMS enligt SS-EN ISO 17294-2:2016 och US EPA Method 200.8:1994. Analys utan föregående uppslutning. Provet är surgjort med 1 ml HNO ₃ (suprapur) per 100 ml före analys. Detta gäller ej prov som varit surgjort vid ankomst till laboratoriet.

Sida : 12 av 12
Ordernummer : LE2101398
Kund : Chalmers Tekniska Högskola



Nyckel: LOR = Den rapporteringsgräns (LOR) som anges är standard för respektive parameter i metoden. Rapporteringsgränsen kan påverkas vid t.ex. spädning p.g.a. matrisstörningar, begränsad provmängd eller låg torrsubstanshalt.
MU = Mätosäkerhet
* = Asterisk efter resultatet visar på ej ackrediterat test, gäller både egna lab och underleverantör

Mätosäkerhet:

Mätosäkerheten anges som en utvidgad osäkerhet (enligt definitionen i "Evaluation of measurement data- Guide to the expression of uncertainty in measurement", JCGM 100:2008 Corrected version 2010) beräknad med täckningsfaktor lika med 2 vilket ger en konfidensnivå på ungefär 95%.

Mätosäkerhet anges endast för detekterade ämnen med halter över rapporteringsgränsen.

Mätosäkerhet från underleverantör anges oftast som en utvidgad osäkerhet beräknad med täckningsfaktor 2. För ytterligare information kontakta laboratoriet.

Utförande laboratorium (teknisk enhet inom ALS Scandinavia eller anlitat laboratorium (underleverantör)).

	Utf.
LE	Analys utförd av ALS Scandinavia AB, Aurorum 10 Luleå Sverige 977 75 Ackrediterad av: SWEDAC Ackrediteringsnummer: 2030

SAMPLE BATCH 1b)



Analyscertifikat

Ordernummer	: LE2101922	Sida	: 1 av 17
Kund	: Chalmers Tekniska Högskola	Projekt	: ---
Kontaktperson	: Ida-Maja Hassellöv	Beställningsnummer	: ---
Adress	: Hörselgången 4	Provtagare	: ---
	: 412 96 Göteborg	Provtagningspunkt	: ---
	: Sverige	Ankomstdatum, prover	: 2021-03-29 22:35
E-post	: ida-maja@chalmers.se	Analys påbörjad	: 2021-03-31
Telefon	: ---	Utfärdad	: 2021-04-08 13:00
C-O-C-nummer	: ---	Antal ankomna prover	: 22
(eller			
Orderblankett-num			
mer)			
Offertnummer	: ST2021SE-CHA-TEK0001 (OF210027)	Antal analyserade prover	: 22

Generell kommentar

Denna rapport får endast återges i sin helhet, om inte utfärdande laboratorium i förväg skriftligen godkänt annat. Laboratoriet tar inget ansvar för information i denna rapport som har lämnats av kunden, eller resultat som kan ha påverkats av sådan information. Beträffande laboratoriets ansvar i samband med uppdrag, se vår webbplats www.alsglobal.se

Signatur	Position
Ilia Rodushkin	Laboratoriechef



Laboratorium	: ALS Scandinavia AB	hemsida	: www.alsglobal.com
Adress	: Aurorum 10	E-post	: info.lu@alsglobal.com
	: 977 75 Luleå	Telefon	: +46 920 28 99 00
	: Sverige		

Sida : 2 av 17
 Ordernummer : LE2101922
 Kund : Chalmers Tekniska Högskola



Analysresultat

Matris: HAVSVATTEN

Provbeteckning

Laboratoriets provnummer

Provtagningsdatum /tid

		108					
		F1 Before MGPS					
		LE2101922-001					
		2021-03-31					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	27.7 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	2.45 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	10.8 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	318	± 32	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	0.306 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	10.4 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	35.6 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	2.45 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	315	± 32	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	898	± 90	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	70.9 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	14.3 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	8160	± 816	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	13.0 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	17.1 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.21 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	67.0 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Sida : 3 av 17
 Ordernummer : LE2101922
 Kund : Chalmers Tekniska Högskola



Matris: HAVSVATTEN

Provbeteckning

Laboratoriets provnummer
 Provtagningsdatum /tid

		109					
		F2 After MGPS					
		LE2101922-002					
		2021-03-31					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	62.0 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.16 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	11.8 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	335	± 34	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	0.0783 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	6.60 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.841 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	340	± 34	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	966	± 97	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	176 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	9.01 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	8590	± 859	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	0.936 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	<0.2 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.20 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	16.2 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Matris: HAVSVATTEN

Provbeteckning

Laboratoriets provnummer
 Provtagningsdatum /tid

		110					
		G1 Before MGPS					
		LE2101922-003					
		2021-03-31					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	12.5 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.81 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	7.63 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	395	± 40	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.05	V-3a	W-SFMS-5D	LE
Co, kobolt	0.0594 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	34.8 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.00602 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	407	± 41	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	1140	± 114	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	1.45 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	12.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	10300	± 1030	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	1.96 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.35 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	3.25 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Sida : 4 av 17
 Ordernummer : LE2101922
 Kund : Chalmers Tekniska Högskola



Matris: HAVSVATTEN

Provbeteckning

Laboratoriets provnummer
 Provtagningsdatum /tid

		111 G2 After MGPS					
		LE2101922-004					
		2021-03-31					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	7.51 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.31 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	7.62 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	400	± 40	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	0.0650 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	12.0 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	78.5 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0262 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	408	± 41	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	1150	± 115	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	1.33 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	13.9 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	10200	± 1020	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	1.49 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	0.682 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.28 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	145 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Matris: HAVSVATTEN

Provbeteckning

Laboratoriets provnummer
 Provtagningsdatum /tid

		112 H After MGPS					
		LE2101922-005					
		2021-03-31					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	7.61 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.91 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	9.97 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	355	± 36	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	380 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0224 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	357	± 36	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	1010	± 101	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	2.07 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	9.77 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	9220	± 922	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	15.7 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	4.95 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.26 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	48.2 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Sida : 5 av 17
 Ordernummer : LE2101922
 Kund : Chalmers Tekniska Högskola



Matris: HAVSVATTEN		Provbeteckning		113				
				I After MGPS				
				LE2101922-006				
				2021-03-31				
Laboratoriets provnummer								
Provtagningsdatum /tid								
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.	
Metaller och grundämnen								
Al, aluminium	11.1 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE	
As, arsenik	2.11 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Ba, barium	16.1 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Ca, kalcium	271	± 27	mg/L	0.2	V-3a	W-AES-1B	LE	
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Co, kobolt	0.0672 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Cu, koppar	173 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE	
Fe, järn	1.84 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE	
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE	
K, kalium	259	± 26	mg/L	0.5	V-3a	W-AES-1B	LE	
Mg, magnesium	745	± 75	mg/L	0.09	V-3a	W-AES-1B	LE	
Mn, mangan	172 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Mo, molybden	7.38 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Na, natrium	6780	± 678	mg/L	0.2	V-3a	W-AES-1B	LE	
Ni, nickel	2.16 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Pb, bly	4.23 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
V, vanadin	1.17 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Zn, zink	45.4 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE	

Metodsammanfattningar

Analysmetoder	Metod
W-AES-02	Analys av metaller i förorenat vatten med ICP-AES enligt SS-EN ISO 11885:2009 och US EPA Metod 200.7:1994 efter uppslutning av prov enligt W-PV-AC.
W-AES-1B	Analys av metaller i förorenat vatten med ICP-AES enligt SS-EN ISO 11885:2009 och US EPA Method 200.7:1994. Analys utan föregående uppslutning. Provet är surgjort med 1 ml HNO ₃ (suprapur) per 100 ml före analys.
W-AFS-17V3a	Analys av kvicksilver (Hg) i förorenat vatten med AFS enligt SS-EN ISO 17852:2008. Analys utan föregående uppslutning. Provet är surgjort med 1 ml HNO ₃ (suprapur) per 100 ml före analys.
W-AFS-17V3b	Analys av kvicksilver (Hg) i förorenat vatten med AFS enligt SS-EN ISO 17852:2008 efter uppslutning av prov enligt W-PV-AC.
W-PV-AC	Upplösning med salpetersyra i autoklav enligt SS 28150:1993 (SE-SOP-0400).
W-SFMS-06	Analys av metaller i förorenat vatten med ICP-SFMS enligt SS-EN ISO 17294-2:2016 och US EPA Metod 200.8:1994 efter uppslutning av prov enligt W-PV-AC.
W-SFMS-5D	Analys av metaller i förorenat vatten med ICP-SFMS enligt SS-EN ISO 17294-2:2016 och US EPA Method 200.8:1994. Analys utan föregående uppslutning. Provet är surgjort med 1 ml HNO ₃ (suprapur) per 100 ml före analys.

Sida : 17 av 17
Ordernummer : LE2101922
Kund : Chalmers Tekniska Högskola



Nyckel: LOR = Den rapporteringsgräns (LOR) som anges är standard för respektive parameter i metoden. Rapporteringsgränsen kan påverkas vid t.ex. spädning p.g.a. matrisstörningar, begränsad provmängd eller låg torrsubstanshalt.
MU = Mätosäkerhet
* = Asterisk efter resultatet visar på ej ackrediterat test, gäller både egna lab och underleverantör

Mätosäkerhet:

Mätosäkerheten anges som en utvidgad osäkerhet (enligt definitionen i "Evaluation of measurement data- Guide to the expression of uncertainty in measurement", JCGM 100:2008 Corrected version 2010) beräknad med täckningsfaktor lika med 2 vilket ger en konfidensnivå på ungefär 95%.

Mätosäkerhet anges endast för detekterade ämnen med halter över rapporteringsgränsen.

Mätosäkerhet från underleverantör anges oftast som en utvidgad osäkerhet beräknad med täckningsfaktor 2. För ytterligare information kontakta laboratoriet.

Utförande laboratorium (teknisk enhet inom ALS Scandinavia eller anlitat laboratorium (underleverantör)).

	Utf.
LE	Analys utförd av ALS Scandinavia AB, Aurorum 10 Luleå Sverige 977 75 Ackrediterad av: SWEDAC Ackrediteringsnummer: 2030

SAMPLE BATCH 2



Analyscertifikat

Ordernummer	: LE2102232	Sida	: 1 av 9
Kund	: Chalmers Tekniska Högskola	Projekt	: Länsvatten
Kontaktperson	: Ida-Maja Hassellöv	Beställningsnummer	: ----
Adress	: Hörselgången 4	Provtagare	: ----
	: 412 96 Göteborg	Provtagningspunkt	: ----
	: Sverige	Ankomstdatum, prover	: 2021-04-13 07:54
E-post	: ida-maja@chalmers.se	Analys påbörjad	: 2021-04-16
Telefon	: ----	Utfärdad	: 2021-04-27 16:18
C-O-C-nummer	: ----	Antal ankomna prover	: 13
(eller Orderblankett-num mer)			
Offertnummer	: ST2021SE-CHA-TEK0001 (OF210027)	Antal analyserade prover	: 13

Generell kommentar

Denna rapport får endast återges i sin helhet, om inte utfärdande laboratorium i förväg skriftligen godkänt annat. Laboratoriet tar inget ansvar för information i denna rapport som har lämnats av kunden, eller resultat som kan ha påverkats av sådan information. Beträffande laboratoriets ansvar i samband med uppdrag, se vår webbplats www.alsglobal.se

Signatur	Position
Ilia Rodushkin	Laboratoriechef



Laboratorium	: ALS Scandinavia AB	hemsida	: www.alsglobal.com
Adress	: Aurorum 10	E-post	: info.lu@alsglobal.com
	: 977 75 Luleå	Telefon	: +46 920 28 99 00
	: Sverige		



Analysresultat

Matris: HAVSVATTEN

Provbeteckning

Laboratoriets provnummer

Provtagningsdatum / tid

201

A

LE2102232-001

2021-04-12

Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	2.87 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	0.797 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	18.7 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	140	± 14	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	13.3 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0135 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	121	± 12	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	345	± 35	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	1.64 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	2.65 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	2950	± 295	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	2.30 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	0.291 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	0.357 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	26.8 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Sida : 3 av 9
 Ordernummer : LE2102232
 Kund : Chalmers Tekniska Högskola



Matris: HAVSVATTEN

Provbeteckning

202

B

Laboratoriets provnummer

LE2102232-002

Provtagningsdatum / tid

2021-04-12

Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	2.61 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.26 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	19.1 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	144	± 14	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	0.0606 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	6.12 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0137 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	125	± 13	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	353	± 35	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	1.62 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	2.90 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	3070	± 307	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	0.894 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	<0.2 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	0.613 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	71.4 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Matris: HAVSVATTEN

Provbeteckning

203

C

Laboratoriets provnummer

LE2102232-003

Provtagningsdatum / tid

2021-04-12

Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	2.82 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.51 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	19.2 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	127	± 13	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	9.80 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0185 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	106	± 11	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	304	± 30	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	1.47 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	2.24 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	2620	± 262	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	0.882 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	<0.2 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	0.318 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	15.7 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Sida : 4 av 9
 Ordernummer : LE2102232
 Kund : Chalmers Tekniska Högskola



Matris: HAVSVATTEN		Provbeteckning		204 D1			
Laboratoriets provnummer				LE2102232-004			
Provtagningsdatum / tid				2021-04-12			
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	43.1 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.61 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	16.4 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	192	± 19	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	0.0589 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	106 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.164 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	184	± 18	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	515	± 52	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	3.94 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	4.20 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	4450	± 445	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	4.20 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	3.26 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	0.525 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	218 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Matris: HAVSVATTEN		Provbeteckning		205 D2			
Laboratoriets provnummer				LE2102232-005			
Provtagningsdatum / tid				2021-04-12			
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	113 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.29 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	16.2 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	192	± 19	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	56.5 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0314 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	182	± 18	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	511	± 51	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	4.09 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	4.40 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	4440	± 444	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	2.40 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	0.358 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	0.512 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	52.2 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Sida : 5 av 9
 Ordernummer : LE2102232
 Kund : Chalmers Tekniska Högskola



Matris: HAVSVATTEN		Provbeteckning	206 E1					
		Laboratoriets provnummer	LE2102232-006					
		Provtagningsdatum / tid	2021-04-12					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.	
Metaller och grundämnen								
Al, aluminium	38.9 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE	
As, arsenik	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Ba, barium	9.62 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Ca, kalcium	23.0	± 2.3	mg/L	0.2	V-3a	W-AES-1B	LE	
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Co, kobolt	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Cu, koppar	7.59 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE	
Fe, järn	0.0356 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE	
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE	
K, kalium	5.10	± 0.51	mg/L	0.5	V-3a	W-AES-1B	LE	
Mg, magnesium	11.2	± 1.1	mg/L	0.09	V-3a	W-AES-1B	LE	
Mn, mangan	6.37 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Mo, molybden	1.12 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Na, natrium	78.7	± 7.9	mg/L	0.2	V-3a	W-AES-1B	LE	
Ni, nickel	2.46 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Pb, bly	<0.2 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
V, vanadin	0.368 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Zn, zink	15.3 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE	

Matris: HAVSVATTEN		Provbeteckning	207 E2					
		Laboratoriets provnummer	LE2102232-007					
		Provtagningsdatum / tid	2021-04-12					
Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.	
Metaller och grundämnen								
Al, aluminium	48.0 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE	
As, arsenik	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Ba, barium	9.11 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Ca, kalcium	35.7	± 3.6	mg/L	0.2	V-3a	W-AES-1B	LE	
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Co, kobolt	0.0574 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Cu, koppar	43.0 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE	
Fe, järn	0.220 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE	
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE	
K, kalium	18.3	± 1.8	mg/L	0.5	V-3a	W-AES-1B	LE	
Mg, magnesium	48.8	± 4.9	mg/L	0.09	V-3a	W-AES-1B	LE	
Mn, mangan	10.8 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
Mo, molybden	1.02 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Na, natrium	417	± 42	mg/L	0.2	V-3a	W-AES-1B	LE	
Ni, nickel	4.15 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE	
Pb, bly	1.91 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE	
V, vanadin	0.286 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE	
Zn, zink	114 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE	

Sida : 6 av 9
 Ordernummer : LE2102232
 Kund : Chalmers Tekniska Högskola



Matris: HAVSVATTEN

Provbeteckning

208

F1

Laboratoriets provnummer

LE2102232-008

Provtagningsdatum / tid

2021-04-12

Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	16.5 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	2.01 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	11.8 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	320	± 32	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	0.0551 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	0.295 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	7.53 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	31.1 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	2.00 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	325	± 33	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	919	± 92	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	63.3 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	14.2 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	8170	± 817	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	13.2 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	16.4 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.04 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	64.6 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Matris: HAVSVATTEN

Provbeteckning

209

F2

Laboratoriets provnummer

LE2102232-009

Provtagningsdatum / tid

2021-04-12

Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	34.6 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.58 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	11.5 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	334	± 33	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	0.0861 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	6.46 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.681 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	345	± 35	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	976	± 98	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	154 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	8.70 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	8490	± 849	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	0.836 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	<0.2 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	0.958 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	15.4 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Sida : 7 av 9
 Ordernummer : LE2102232
 Kund : Chalmers Tekniska Högskola



Matris: HAVSVATTEN

Provbeteckning

210

G1

Laboratoriets provnummer

LE2102232-010

Provtagningsdatum / tid

2021-04-12

Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	10.8 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	2.09 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	7.65 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	401	± 40	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	36.1 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.00865 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	417	± 42	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	1170	± 117	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	0.729 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	12.6 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	10100	± 1010	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	0.505 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	1.78 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.37 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	3.11 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Matris: HAVSVATTEN

Provbeteckning

211

G2

Laboratoriets provnummer

LE2102232-011

Provtagningsdatum / tid

2021-04-12

Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	4.78 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.64 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	8.06 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	400	± 40	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	0.0724 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	10.9 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	82.8 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0250 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	420	± 42	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	1170	± 117	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	1.58 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	14.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	10500	± 1050	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	2.31 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	0.640 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.34 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	161 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Sida : 8 av 9
 Ordernummer : LE2102232
 Kund : Chalmers Tekniska Högskola



Matris: HAVSVATTEN

Provbeteckning

212

H

Laboratoriets provnummer

LE2102232-012

Provtagningsdatum / tid

2021-04-12

Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	5.47 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	1.82 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	9.26 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	358	± 36	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	<0.05 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	446 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	0.0254 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	372	± 37	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	1040	± 104	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	1.57 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	9.26 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	9340	± 934	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	21.2 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	5.62 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.18 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	47.0 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE

Matris: HAVSVATTEN

Provbeteckning

213

I

Laboratoriets provnummer

LE2102232-013

Provtagningsdatum / tid

2021-04-12

Parameter	Resultat	MU	Enhet	LOR	Analys paket	Metod	Utf.
Metaller och grundämnen							
Al, aluminium	8.68 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE
As, arsenik	2.08 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Ba, barium	16.1 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Ca, kalcium	271	± 27	mg/L	0.2	V-3a	W-AES-1B	LE
Cd, kadmium	0.0770 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Co, kobolt	0.105 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Cr, krom	<0.5 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Cu, koppar	170 *	----	µg/L	1.0	V-3a	W-SFMS-5D	LE
Fe, järn	1.79 *	----	mg/L	0.00400	V-3a	W-SFMS-5D	LE
Hg, kvicksilver	<0.02	----	µg/L	0.02	V-3a	W-AFS-17V3a	LE
K, kalium	262	± 26	mg/L	0.5	V-3a	W-AES-1B	LE
Mg, magnesium	753	± 75	mg/L	0.09	V-3a	W-AES-1B	LE
Mn, mangan	146 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
Mo, molybden	6.75 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Na, natrium	6670	± 667	mg/L	0.2	V-3a	W-AES-1B	LE
Ni, nickel	2.21 *	----	µg/L	0.50	V-3a	W-SFMS-5D	LE
Pb, bly	4.08 *	----	µg/L	0.20	V-3a	W-SFMS-5D	LE
V, vanadin	1.25 *	----	µg/L	0.050	V-3a	W-SFMS-5D	LE
Zn, zink	47.2 *	----	µg/L	2.0	V-3a	W-SFMS-5D	LE



Metodsammanfattningar

Analysmetoder	Metod
W-AES-1B	Analys av metaller i förorenat vatten med ICP-AES enligt SS-EN ISO 11885:2009 och US EPA Method 200.7:1994. Analys utan föregående uppslutning. Provet är surgjort med 1 ml HNO ₃ (suprapur) per 100 ml före analys.
W-AFS-17V3a	Analys av kvicksilver (Hg) i förorenat vatten med AFS enligt SS-EN ISO 17852:2008. Analys utan föregående uppslutning. Provet är surgjort med 1 ml HNO ₃ (suprapur) per 100 ml före analys.
W-SFMS-5D	Analys av metaller i förorenat vatten med ICP-SFMS enligt SS-EN ISO 17294-2:2016 och US EPA Method 200.8:1994. Analys utan föregående uppslutning. Provet är surgjort med 1 ml HNO ₃ (suprapur) per 100 ml före analys.

Nyckel: LOR = Den rapporteringsgräns (LOR) som anges är standard för respektive parameter i metoden. Rapporteringsgränsen kan påverkas vid t.ex. spädning p.g.a. matrisstörningar, begränsad provmängd eller låg torrsubstanshalt.

MU = Mätosäkerhet

* = Asterisk efter resultatet visar på ej ackrediterat test, gäller både egna lab och underleverantör

Mätosäkerhet:

Mätosäkerheten anges som en utvidgad osäkerhet (enligt definitionen i "Evaluation of measurement data- Guide to the expression of uncertainty in measurement", JCGM 100:2008 Corrected version 2010) beräknad med täckningsfaktor lika med 2 vilket ger en konfidensnivå på ungefär 95%.

Mätosäkerhet anges endast för detekterade ämnen med halter över rapporteringsgränsen.

Mätosäkerhet från underleverantör anges oftast som en utvidgad osäkerhet beräknad med täckningsfaktor 2. För ytterligare information kontakta laboratoriet.

Utförande laboratorium (teknisk enhet inom ALS Scandinavia eller anlitat laboratorium (underleverantör)).

	Utf.
LE	Analys utförd av ALS Scandinavia AB, Aurorum 10 Luleå Sverige 977 75 Ackrediterad av: SWEDAC Ackrediteringsnummer: 2030



CHALMERS