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Securing the functionality of sea water intakes in ice operation

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Securing the functionality of seawater intakes in ice operation

The functionality of seawater systems in ice-going ships are constantly improved so that the operating in ice conditions would be safe and stable. Challenging ice conditions where the ship is sailing through ice slush or brash ice can cause problems with the seawater intake as the ice can get inside and cause a blockage.

This thesis focuses on the separate seawater intake, that is built in ships where the emergency fire pump needs to have an independent pumping system and intake, or it needs to be outside the machinery spaces according to the regulations. Emergency fire pumps are critical consumers, and their function needs to be secured for fire safety. It can be built also because of practical reasons, having it can make the pipelines shorter as the separate seawater intake can be closer to consumers.

The thesis consists of information about the physics of ice and an overview of the seawater system. After that the separate seawater intake is discussed in-depth with two real-life references. This thesis was commissioned by Aker Arctic Technology Inc.

Example calculations were made to estimate the power requirement to keep the separate seawater intake ice free as well as calculations about specific de-icing methods. In addition to the de-icing methods, other ways to prevent the icing were researched such as geometry and location in the ship.

Keywords:

Sea ice, Ice breakers, Ship machinery, Emergency fire pumps, Seawater systems

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Meriveden erilliskaivon toiminnan turvaaminen jääoperoinnissa

Jäissä kulkevien laivojen merivesijärjestelmien käyttövarmuutta pyritään parantamaan suunnittelun keinoilla, jotta jääolosuhteissa operointi olisi turvallista ja vakaata. Haasteita operointiin tuovat hankalat olosuhteet, joissa laiva kulkee sohjossa tai pirstaleisessa jäässä ja siten merivesikaivoon kulkeutuva jää voi aiheuttaa tukoksen kaivossa tai putkistossa.

Tämän opinnäytetyön kohteena on laivan erillismerivesikaivo, joka on laivoissa, joissa säännösten mukaan tarvitaan hätäpalopumpulle oma pumppaussysteemi tai hätäpalopumppu täytyy sijoittaa laivan konehuonetilojen ulkopuolelle. Hätäpalopumppu on kriittinen kuluttaja, jonka toiminta tulee turvata kaikissa tilanteissa paloturvallisuuden vuoksi. Myös käytännön näkökulmat, kuten pitkien putkilinjojen lyhentäminen voi olla peruste erillismerivesikaivon rakentamiselle.

Opinnäytetyössä käsitellään myös jään fysikaalisia ominaisuuksia, sekä perehdytään merivesijärjestelmään kokonaisuutena. Näiden teoriatietojen jälkeen perehdytään tarkemmin erillismerivesikaivojen ominaisuuksiin kahden oikean elämän esimerkkitapauksen kautta. Opinnäytetyön toimeksiantaja on Aker Arctic Technology Oy.

Esimerkkitapauksiin pohjaten tehtiin karkeita esimerkkilaskelmia vaadittavasta lämmitystehosta ja siitä millaisin keinoin lämmitystä kaivoille voitaisiin tuoda. Jäänsulatusmenetelmien lisäksi käsitellään myös muita keinoja, joilla sohjoontumisongelmat voitaisiin estää, kuten geometria ja sijoittelu laivassa.

Asiasanat:

Merijää, Jäänmurtajat, Laivan koneistot, Hätäpalopumput, Merivesi järjestelmät,

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List of abbreviations and symbols

CAD	Computer Aided Design
FISCAR	Finnish-Swedish Ice Class Rules
HT	High Temperature
IMO	International Maritime Organization
LT	Low Temperature
SOLAS	International Convention For Safety Of Life At Sea
PLC	Programmable Logic Controller
GA	General Arrangement

<u>Symbols</u>

$\dot{m}$	mass flow
C_i	specific heat capacity of ice
C_w	specific heat capacity of water
ρ_i	density of ice
ρ_w	density of water
L	fusion heat of ice
Q	heating energy
Q_p	heating power
T1	start temperature of ice
T2	start temperature of water
T3	desired temperature

σ	concentration of ice in water
$\dot{V}$	volumetric flowrate
Q	heat transfer rate
U	overall heat transfer coefficient
A	heat transfer area
ΔT_m	log mean temperature difference
T_1	inlet temperature of heating substance
t_1	inlet temperature from separate seawater intake
T_2	return temperature of heating substance
t_2	return temperature to separate seawater intake

1 Introduction

The seawater system of ice going ships is a detrimental part of the ship's systems and constant developments in this area are needed to ensure the functionality and safety of the ship. In this thesis the seawater system is introduced as whole along with physics of ice, but the focus is on the separate seawater intake. By having a basic understanding about the physical properties of ice and the overhaul of the seawater system, the reader can understand the fundamental problems that arise in the separate seawater intake.

A common problem among many ice-going ships is the sea chests gathering ice and losing functionality when it causes a blockage in the system. In the ice chest systems designers have implemented systems to prevent these problems, but the separate seawater system is often overlooked while facing the same problems. Even if the separate seawater system is considered more in the design, problems still cannot always be solved completely due to space restrictions or several other obstacles.

Resolving these problems could require solutions that are more complicated and taking an in-depth look into the possibilities for improvement, within the limitations of ship. Some design improvements are introduced and compared in this thesis, along with examples and calculations from real-world cases and discussions with experts in this field.

2 Physics of ice

Ice is a solid form of water. In natural conditions, ice forms into a hexagonal crystalline structure. Therefore, ice in snow, lakes, and glaciers also has a hexagonal crystalline structure. On the contrary, ice with alternative crystalline structures forms only in a laboratory setting with extremely low temperatures and high pressure.

An exceptional feature of ice is that it is notably less dense than liquid water compared to how most substances exhibit the opposite behavior, with the solid form being more dense than the liquid form. The cause of this phenomenon is that when water freezes and turns into ice, its hydrogen bonds stabilize into a hexagonal lattice structure, where the orientation of the molecules is more dispersed than in the arrangement in liquid water. Ice is nearly 10 % less dense than liquid water, which causes it to float on the water. In addition, when water freezes and turns into ice, its density decreases while its volume expands. Freezing in restricted spaces causes intense pressures due to volume increase.

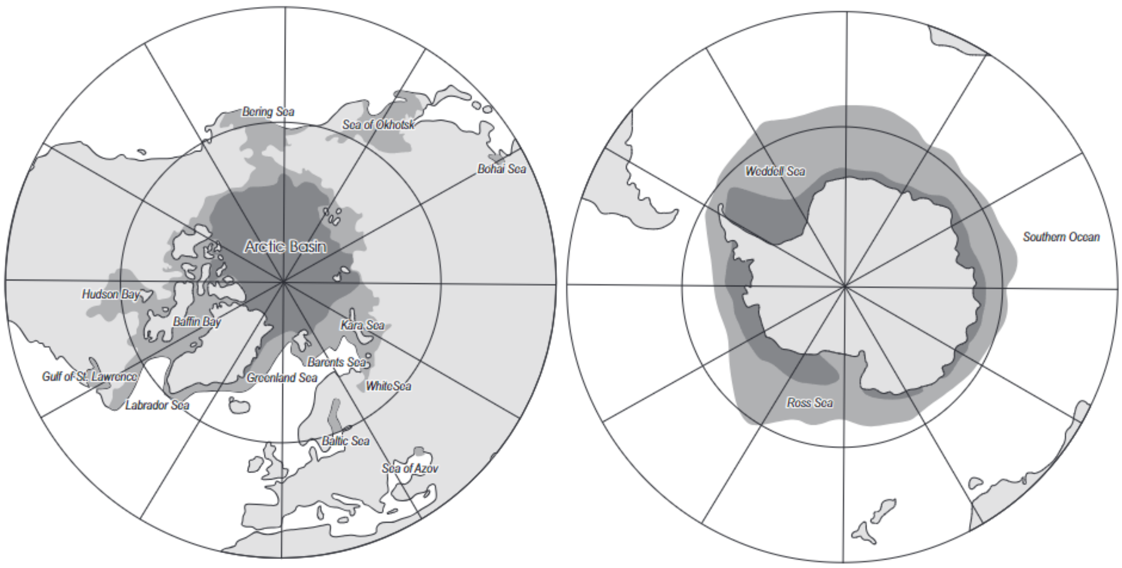
The freezing point of clean water is 0 °C in standard atmospheric pressure (1,01325 bar). The freezing point can decrease by two factors: pressure and concentration. For example, seawater freezes at a lower temperature than freshwater due to the higher salt concentration. However, pressure doesn’t have a notable impact on the freezing point in nature.

When water reaches its standard freezing point, crystallization begins around nucleation sites or impurities. Water will stay liquid and not undergo a phase transition into a solid state when lacking the freezing nucleus. That state is undercooling, which is a temporary state, and the liquid will then solidify. (Korhonen J. 2005, 17.)

Water occurs in nature in all its three forms: solid, gas, and liquid. Therefore, it has an exact temperature-pressure point where all the phases are in equilibrium i.e. a triple point. The triple point of water is at 0,01 °C, and 6,117 mbar. This set of values is exact and even small shifts in pressure or temperature transform water into only one form. (Leppäranta et al. 2017, 39.)

2.1 Sea ice

Sea ice is frozen seawater and the mass bases in polar regions at high latitudes. The world's ice cover is divided into the perennial ice zone and the seasonal ice zone. In picture below perennial ice zone is shown in dark grey and the seasonal ice zone in lighter grey.



Picture 1. Ice zones. (The Drift of Sea Ice 2010, 14)

In the central part of the Arctic Ocean and around the continent of the Antarctic, the sea ice lasts throughout the entire year, which makes it the perennial ice zone. Sea ice forms and melts on a seasonal basis in the seasonal ice zone, and it covers areas from the Baltic Sea and White Sea to the Sea of Okhotsk, Bering Sea, Hudson Bay, Gulf of Saint Lawrence, and Labrador Peninsula. (Leppäranta, M. 2010, 11)

The main aspects of sea ice are its age, thickness, and quality. These aspects depend on each other; as the ice ages, its thickness and strength increase. The development of sea ice usually happens in four stages. Recently formed ice is new ice and when the ice reaches a thickness of 10-30 centimeters, it turns into young ice. First-year ice is grown no more than one year, and its thickness is 30 centimeters to 2 meters. Ice with more than one year’s growth is multi-year ice and has a thickness of over two meters.

Ice grows its thickness through three different mechanisms. The first way is when ice grows from underside of the ice sheet, forming coagulated ice. Secondly ice can increase from the top surface as the slush on top of the ice freezes. Lastly, ice can grow in open water when frazil ice forms from undercooled water. Frazil ice consists of fine needle-like ice crystals that cluster. (Myberg & Leppäranta. 2014 66-67)

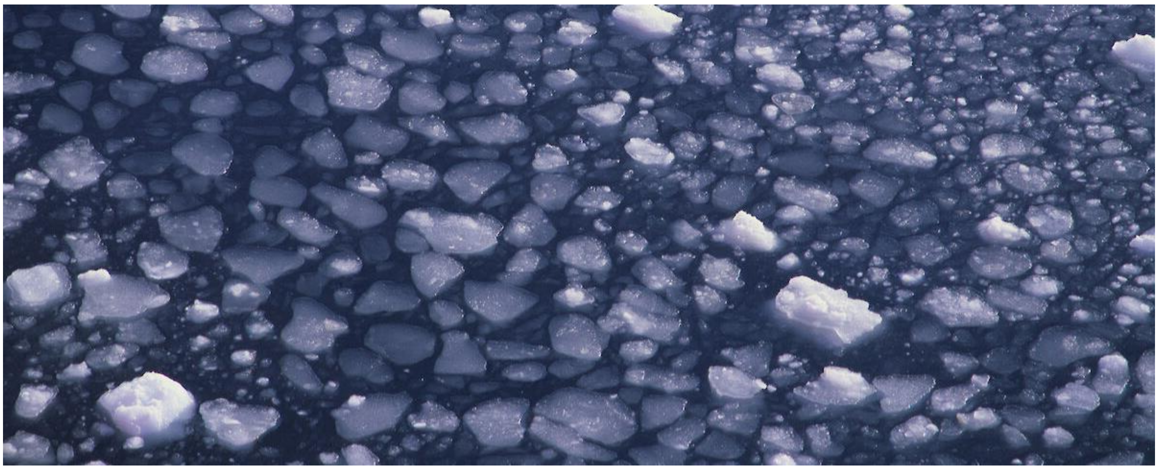
2.2 Ice quality

The quality of sea ice is defined by the appearance of the characteristics of sea ice formations. A fundamental aspect of sea ice is its attachment to land; landfast ice is solid, even ice fastened along the coastline or archipelago, while drift ice is not connected to land and flows by wind and sea currents. Drift ice is highly dynamic and constantly reforming due to mechanical strain.

Ice field is an area full of drift ice, reaching at least 10 kilometers across. When ice floes get in contact with each other, a variety of ice qualities form.

Picture 2. Brash ice field. (Australian government 2017)

As ice floes drift on top of each other and pile up, various types of pressure ice form. Rafted ice forms when large ice floes collide, overlap and interlock with each, causing a layered appearance and a raft-like structure. On the other hand, brash ice refers to accumulation of small fragments of sea ice resulting from breaking or grinding off larger ice masses.



Picture 3. Brash ice. (Australian government 2017)

Hummocked ice forms when ice floes or sheets impact by forces that causes them to buckle, crack and pile haphazardly, creating an uneven ice surface.

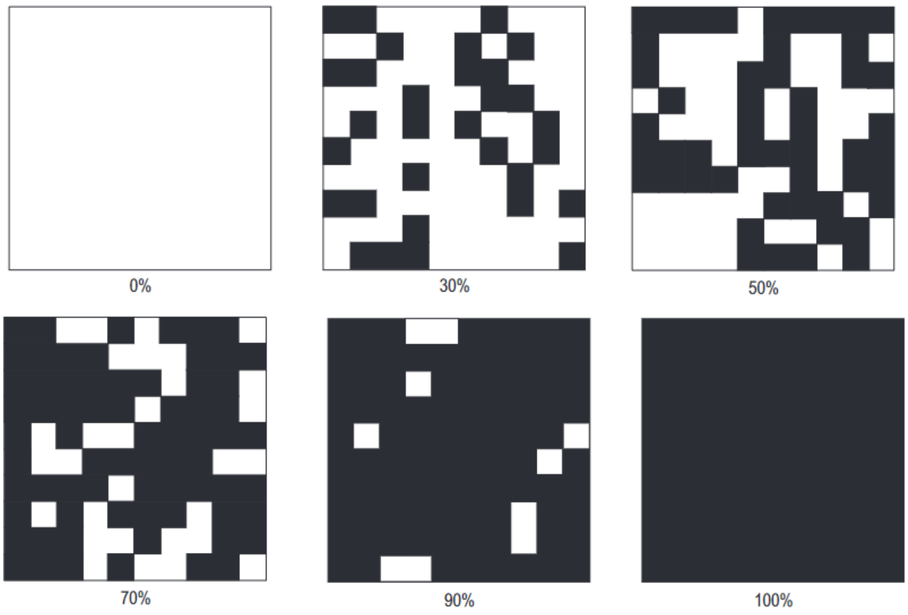
2.3 Ice compactness

The amount of drift ice and open water is depicted by ice compactness (A), which means the area of the ice cover. The values are given in percentages and categorized into six standard classes.

Table 1. Verbal and numerical depictions of ice compactness. (The Drift of Sea Ice 2010, 17

Verbal	Numerical	Verbal	Numerical
Ice free	$A = 0\%$	Very open drift ice	$0\% < A < 30\%$
Open drift ice	$30\% \leq A < 50\%$	Close drift ice	$50\% \leq A < 70\%$
Very close drift ice	$70\% \leq A < 90\%$	Compact drift ice	$90\% \leq A \leq 100\%$

The compactness of the drift ice can alter easily, especially in open drift ice, where ice floes can drift freely without being attached to each other. In very close drift ice, internal friction keeps the floes together even in strong winds.



Picture 4. Binary chart depictions of ice compactness. (The Drift of Sea Ice 2010, 19)

Ice compactness can be illustrated by binary charts in addition to verbal depictions. (Leppäranta M. 2010, 19)

3 Seawater system

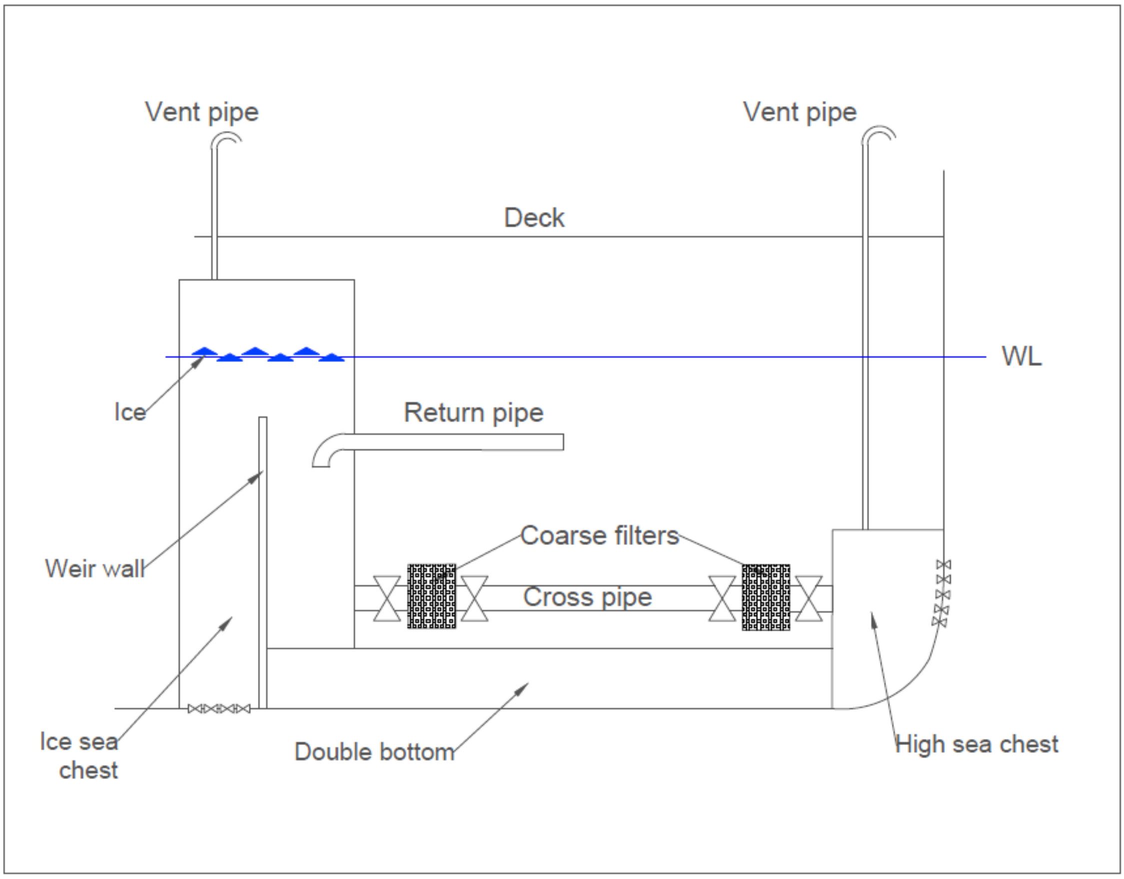
The main function of a seawater system in a ship is to supply cooling water to engines and propulsion machinery. Ice-going ships typically have one of the two cooling systems: traditional seawater cooling system with an ice-chest(s) or a box cooler system. A ship's size, its features, and the sailing environment, are some of the decisive factors in choosing the seawater cooling system for the ship.

Ice-going ships have an ice chest, to supply the seawater system with seawater. The system can also include an optional separate seawater intake for other seawater consumers. Box coolers also operate in seawater as they are cooled by it, but they are not a part of the seawater supply system because they operate with closed freshwater system. In this chapter, the structure of the seawater system is introduced by briefly explaining the function of the ice chest and the box cooler and then discussing the separate seawater intake and its regulations in more detail, as it is the main subject of this thesis.

3.1 Ice sea chest

Ice chest is a crucial part of seawater cooling system in ice-going ships. Ice chest ensures that seawater supply for cooling of the main machinery is maintained in conditions.

According to the Finnish-Swedish Ice Class Rules (FSICAR), a ship with I A ice class or higher, the ice sea chest is required. I A ice class means that the vessel has a structure, engine power, and other characteristics such that it can navigate in challenging ice conditions as needed with the assistance of an icebreaker. (Finlex 22.12.2005/1121, 3:2)



Picture 5. Layout of typical ice sea chest

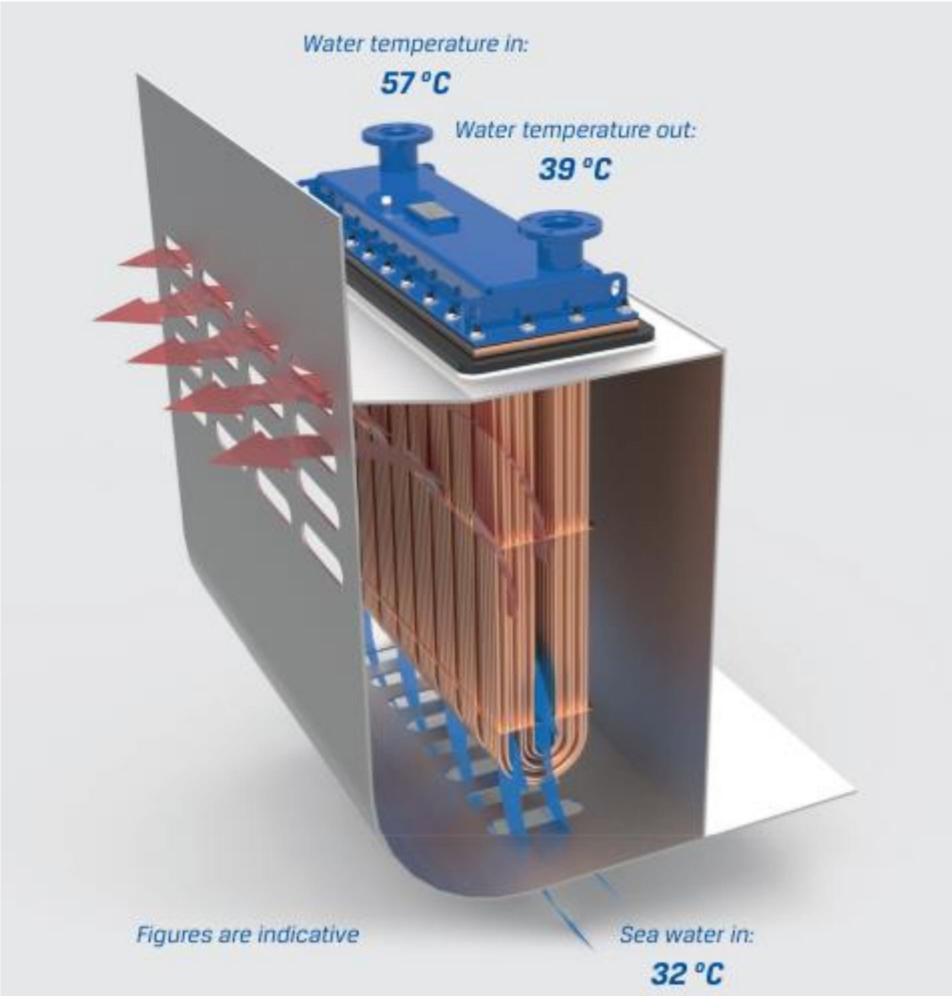
In the layout picture above, the ice sea chest is a tall chamber, and its structure extends above the waterline. On the water line of the ice sea chest there is ice floating. The weir plate is placed so that it guides ice pieces to the waterline and thus prevents the entry to the suction inlet. As the water goes from the ice sea chest to the engine it warms up the water. The warm water then goes back to the ice sea chest instead of dispensing it into the sea. This type of cycling ensures that the ice sea chest remains unfrozen and operational.

In the layout, the ice sea chest is the tall low-suction sea chest, and parallel to it is a small high-suction sea chest. The high-suction sea chest is most used in ports and other shallow waters, as it is not near the bottom of the sea in these situations. The seawater is led from the sea chests to valves to the cross pipe and the coarse filters and then into to the seawater cooling pumps. (Sjögren, H. 2016, 29-30)

3.2 Box cooler

Box cooler is an alternative means to engine cooling, installed within the ship's hull in a rectangular-shaped enclosure. Inside of it is fitted a U-tube bundle. It circulates fresh water that is used to cool the engines. The enclosure has an inlet and outlet port for seawater circulation. The seawater circulation then cools the U-tube bundle, thus cooling the water circulating in the U-tube bundle.

HT (High Temperature) water and LT (Low Temperature) water comes from the machinery that runs through the U-tube bundle as the tubes immerse in cold seawater, and the temperature reduces inside the tubes. The cooling effect is achieved by utilizing thermal flow. The buoyancy of the heated seawater creates the seawater flow through the box cooler. The flow velocities are typically small and differences in temperature proportionally small. The forced circulation around the bilge as the vessel moves forward determines the circulation.



Picture 6. Structure of a box cooler. (Llalco Fluid Technology Catalog)

Lower weight, lower installation costs, easier maintenance, and higher reliability in shallow or muddy waters are advantages compared to conventional cooling systems.

The reason to use box coolers instead of a conventional cooling system in small sized ships is often lack of space. Box coolers are capable of cooling diesel engines up to 30 000 kW, while larger power references are rarer.

Box coolers have many convenient aspects to them, the sensitivity organic growth and galvanic corrosion are some of the more negative traits to be considered. The combination of surface coatings and galvanic protection are the methods to minimize the risks of malfunction. (Árughadhoss, S. 2008 6-7)

In ice conditions, there is a possibility of the box cooler filling up with ice slush. This usually happens when the ship is sailing through a floe of slush ice, that reaches under the bottom of the ship. Ice slush goes into the box cooler enclosure along with the thermal flow. Some of the interviewees for this thesis have confirmed this to be a possible problem for box coolers. (Jaatinen, J. interview 16.4.2024)

3.3 Separate sea water intake

The separate sea water intake is the secondary seawater inlet alongside the ice sea chest in a ship. Consumers of the separate seawater intake can be some of the following: ballast pump, freshwater generator seawater pump, emergency fire pump, or a local cooling system. All ships do not have this seawater intake, but it can be required by IMO (International Maritime Organization) SOLAS (International Convention for the Safety of Life at Sea) in some cases. Those requirements are introduced in detail later in this chapter.

The separate seawater intake usually has quite a small opening to the sea, about a little less than one square meter, and the height usually is around 1,5 meters. The opening has a grid to it with 20 millimeters wide holes.

The location of the separate seawater intake is generally in the midship area or in the bow. The location can even be on the bilge next to the ship's side or in the ship's stern. The amount of the water that the separate seawater supplies is only a small portion of the total amount of the seawater the ship takes in. When comparing the separate seawater intake to ice sea chest, it is much smaller since the amount of water that goes through is lower.

The separate seawater intake can also benefit the ship’s general arrangement. It can make the general arrangement of the vessel better if it is near the consumers, compared to the situation where the consumers must take the seawater from the engine room, which can be far apart. So, having separate seawater intake can help by making the pipelines shorter.

Heating systems, such as steam circulation, can be built in separate seawater intakes to prevent icing and to keep it operational. By utilizing the de-icing arrangement, the problem with icing or slushing can be avoided or mitigated. There are many ways to execute the de-icing arrangement, and this study investigates the possibilities within the de-icing.

3.3.1 SOLAS regulations concerning separate seawater intake

There are several regulations in SOLAS, that can be applied to the separate sea water intake onboard. The regulations determine the concerns of fire safety by prescribing the rules to the location and space requirements as well as the need for independently driven pumps. The mission of the regulations is to make the vessel safer by limiting the possibility and severity of fire hazards.

Regarding emergency fire pumps there is passage in SOLAS in Chapter II-2, regulation 52 point (ii):

‘’(ii) In a ship of 1,000 tons gross tonnage and upwards if a fire in any one compartment could put all the pumps out of action, there must be an alternative means of providing water for firefighting. In a ship of 2,000 tons gross tonnage and upwards this alternative means shall be a fixed emergency pump independently driven. This emergency pump shall be capable of supplying two jets of water to the satisfaction of the Administration.’’

According to the regulation above-mentioned, in a ship of 1000 gross tons and upwards, there needs to be two ways of providing water for the fire pumps in separate compartments for safety reasons. For example, if a fire breaks out in a compartment where the ice sea chest is located, an alternative pump in separate compartment needs to be able to provide water for the pumps. Ships of 2000 gross tonnage and upwards need the fire pumps to be independently driven along with separate from the other pumps.

There is also another paragraph in SOLAS that states that the emergency fire pump’s space requirements in Chapter II-2, regulation 11, point (e):

‘’(e) The pump shall be capable of simultaneously supplying at the necessary pressure all sections of the system in any one compartment to be protected. The pump and its controls shall be installed outside the space or spaces to be protected. It shall not be possible for a fire in the space, or spaces protected by the water-spraying system to put the system out of action.’’

Paragraphs regarding the fire pumps and their locations have been regulated in SOLAS Chapter II-2, Part C Reg. 10:

2.2.3.1 Fire pumps

‘’The arrangement of sea connections, fire pumps and their sources of power shall be as to ensure that:

.1 in passenger ships of 1,000 gross tonnage and upwards, in the event of a fire in any one compartment all the fire pumps will not be put out of action; and .2 in passenger ships of less than 1,000 gross tonnage and in cargo ships, if a fire in any one compartment could put all the pumps out of action, there shall be an alternative means consisting of an emergency fire pump complying with the provisions of the Fire Safety Systems Code with its source of power and sea connection located outside the space where the main fire pumps or their sources of power are located.’’

2.2.3.2.2 Access to the emergency fire pump

‘’No direct access shall be permitted between the machinery space and the space containing the emergency fire pump and its source of power. When this is impracticable, the Administration may accept an arrangement where the access is by means of an airlock with the door of the machinery space being of "A-60" class standard, and the other door being at least steel, both reasonably gastight, self-closing and without any hold-back arrangements. Alternatively, the access may be through a watertight door capable of being operated from a space remote from the machinery space and the space containing the emergency fire pump and unlikely to be cut off in the event of fire in those

spaces. In such cases, a second means of access to the space containing the emergency fire pump and its source of power shall be provided.''

4 Challenges in ice operation

Ice-going vessels face a variety of difficulties while moving through ice fields. This study focuses on problems regarding the functionality of separate seawater intake. The main issue with the separate seawater intake is that it can fill up with icy slush under certain conditions. This chapter discusses the main mechanisms of how ice can clog the separate seawater intake: brash ice or slush ice can accumulate by currents into the separate seawater intake, or undercooled water can become slush ice when the triple point shifts even slightly by the pressure changes or shock to the hull.

When the separate seawater intake clogs with ice, pumps shut off, and water cannot be supplied to the consumers, such as ballast pumps, freshwater generator seawater pumps, emergency fire pumps, and local cooling systems. It leads to situations where detrimental functions on the ship reach a standstill. In the worst case, the emergency fire pump shuts down and causes a fire protection risk.

This study takes a closer look at two real-life cases provided by Aker Arctic where the separate seawater intakes' functionality is compromised and discusses the causes of the problems. Both cases demonstrate the typical build of the separate seawater intake, even though slightly differing from each other. This thesis compares how the different types of structures can affect the functionality of the separate seawater intake.

4.1 Ice accumulating by drifting

Tiny fractures of ice, so-called brash ice, or ice in slush-type consistency, can easily drift into the separate seawater intake despite having the bottom grid. The bottom grid prevents the bigger particles from entering the separate seawater intake, so everything smaller than 20mm can flow in along with water.

Sailing in open drift ice and heavily operated areas usually tends to have a lot of ice slush or brash ice that can easily flow into separate seawater intake. The same thing applies to the ports since the broken ice can often reach the bottom of the harbor basin. (Hänninen, T. interview 4.4.2024)

Placement of the separate seawater intake in the bow can be more prone to the ice drifting into the system. It is most likely due to the tendency of the fine brash ice to drift under the ship as the bow meets the ice and forces the ice under the ship. Compared to when the sea chest is further away along the bottom of the ship, most of the ice would have floated up to the waterline. (Jaatinen, J. interview 16.4.2024)

4.2 Undercooled water turning into ice

Ice can drift along the water into the separate seawater intake, but it is also possible that the ice formation happens inside the intake or the piping. When water is below 0 °C and in an undercooled state, only a slight drop in pressure or light shock can turn the liquid water into solid form. Brash ice or ice slush inside a separate seawater intake can be a freezing nucleus for undercooled water.

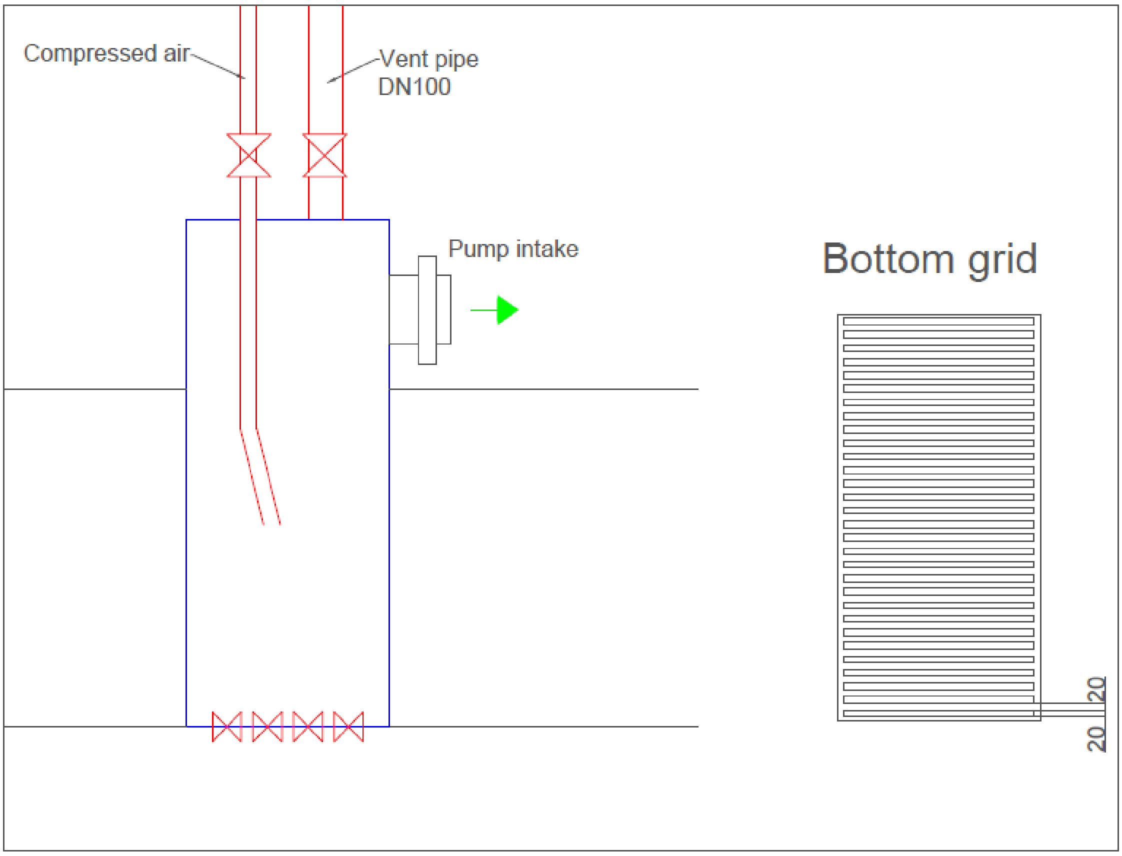
Other factors that can lead to the undercooled water turning into ice are negative pressure and adiabatic cooling. The pump's suction or the venturi effect causes negative pressure. The venturi effect is a phenomenon where the reduction of the cross-sectional area of a pipe accelerates water flow and thus lowers its pressure to keep the gross flow of liquid the same throughout the piping. On the other hand, adiabatic cooling is the process of temperature lowering due to a rapid increase in its flow velocity without the temperature of surroundings changing. (Häkkinen, P. interview 27.2.2024)

4.3 Examples of the separate seawater intake

The purpose of introducing two examples of the separate seawater intake is to demonstrate the existing systems and their features and problems that have occurred with them. As there is lack of published information of the separate seawater intake, it is necessary to introduce references with calculations. The references give an idea with visual representation, what a separate seawater intake can be like. CAD (Computer Aided Design) images of the layouts are drawn in Autodesk AutoCAD in reference to schematics given by Aker Arctic.

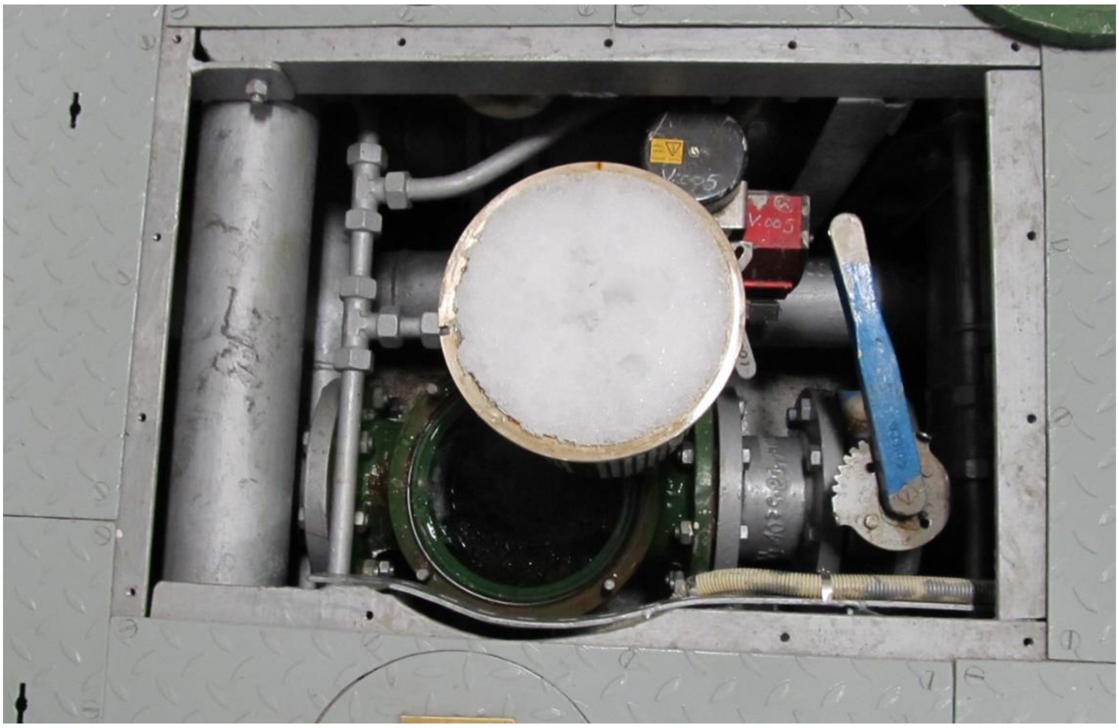
4.3.1 Ship case 1

The ship operates in shallow waters and has a separate seawater intake in the midship area. Main machinery is cooled by box coolers. The upper side of the separate seawater intake is against a warm space and three sides are against a ballast water tank, the end side is against a dry space. The bottom has a rectangular shape.



Picture 7. Layout of the 1st case.

The three consumers of the ship's separate seawater are ballast pump, freshwater generator seawater pump and fire pump. Total consumption of the consumers is 175 m^3/h, while maximum consumption of a single consumer is 65 m^3/h. Cross-sectional area of the separate seawater intake is about 1 m^2 and the water volume 1 m^3.



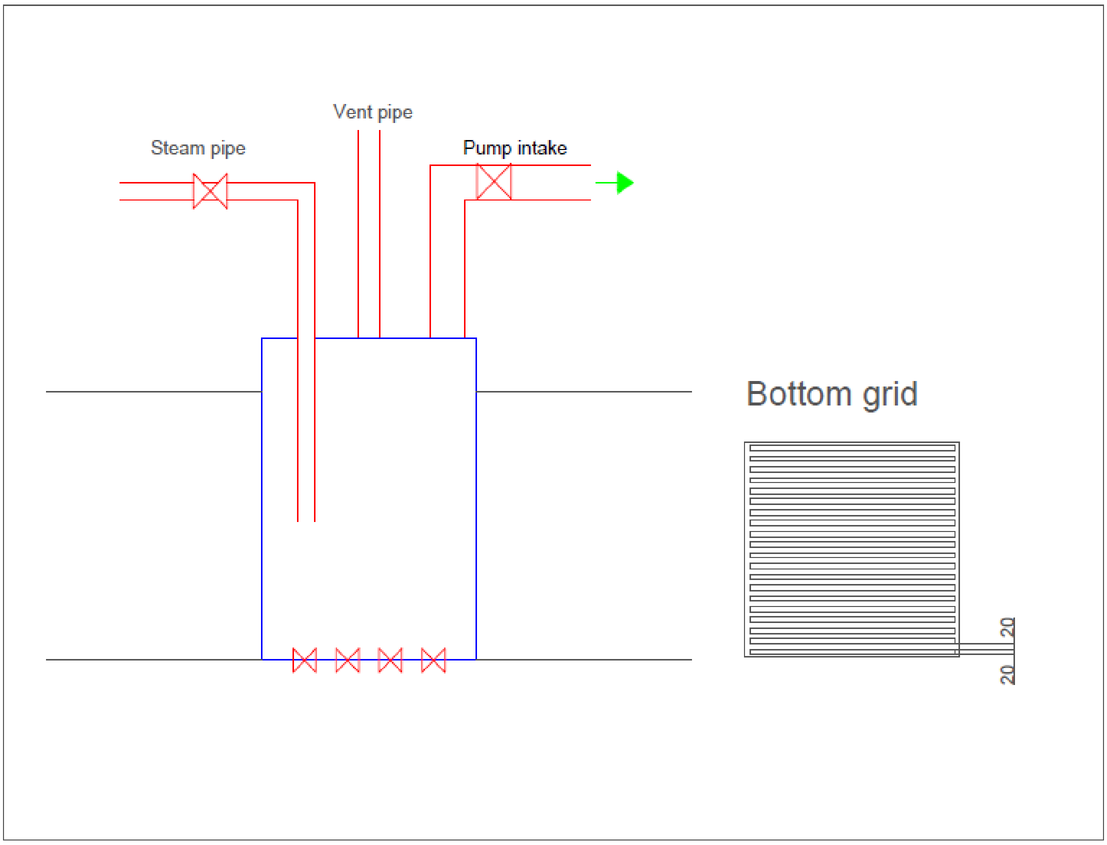
Picture 8. Filter after 1 hour sailing in ice.

In a demonstration test the problem with the separate seawater intake was that the seawater filter accumulated ice, forcing the pumps to stop. The seawater filter got clogged by ice after the ship had sailed through an ice field for one hour, after which the pumps ran for a few minutes.

4.3.2 Ship case 2

In the ship of the second case the separate sea water intake is in the rear portion of the midship and supplies consumers such as emergency fire pump. Cooling for the engine comes from ice sea chest. The sides of the separate seawater intake are against bilgewater tank, and the top is against a warm space of with minimum temperature of 5 °C. It is not known if the bilgewater tanks were empty or filled with water when problems occurred.

The structure of the separate sea water intake is designed so that the pump intake is at the top of the chest along with all the other connections and pipes, except for the steam pipe which extends deeper into the chest. The chest has a rectangular shape.



Picture 9. Layout of the 2^{nd} case.

In one separate seawater intake case, the problem was ice blockage in the filter of the seawater pipeline behind the separate seawater intake, like in ship case 1. During some a scale model ice testing it was also found that some ice drifts under the hull of the ship all the way to the separate seawater intake, which could cause ice to get sucked in to the separate seawater intake.

In this case, there was only given one consumer, which is the emergency fire pump. The emergency fire pump consumes 70 m^3/h. Cross-sectional are of the seawater intake is about 0,6 m^2 and the water volume about 0,8 m^3.

5 Improvements to the design

This chapter discusses the possible improvements to the designs and investigates preventative measures, focusing on the ways to prevent and detect the problems associated with the separate seawater intake. The efficiency of the de-icing methods is studied and how they can be implemented on the separate sea water intake.

There are already existing methods and common practices that are being used in currently active ships. These methods are introduced in this chapter and evaluated based on expert interviews and previous cases. Possible improvements to existing methods are investigated in this chapter.

This chapter also investigates ways to gather information about the phenomenon inside the separate seawater intake to further develop the sea chest in the future.

5.1 Location

The location of the separate seawater intake is important when considering the ways to prevent the ice drifting into the separate seawater intake. The location can be taken into consideration when making the GA (General Arrangement) of a new built ship, whereas changing the location on the already existing ship would be difficult.

The ship type and size can have limitations about where the separate seawater intake would be located, but generally it would be best located into the double bottom as in the midship area and as deep as possible. The placement in midship area would be less likely to gather the ice same way that in the bow, as the ice will have time to float to waterline before reaching the intake. When placed in stern, the propellers might cause a problem with causing currents in the area. (Hänninen, T. interview 4.4.2024)

Having a separate seawater intake as deep in the bottom as possible would be preferred because most of the ice will be at the waterline or slightly below it. If the ship has a shallow draught, it has a higher chance of getting ice slush inside the intake than a ship with deeper draught, because with deeper draught the intake can also be deeper in the water. Also having the separate seawater intake in the middle would be better than in the side of the ship as it would be more affected by waves and the surrounding temperature of the seawater outside the ship. (Henriksson, R. interview 10.4.2024)

By taking these factors into account when designing a new vessel, the problems can be minimized within the limitations of the ship type. In some cases, the location would be better in the bow in terms of being closer to the consumers such as emergency fire pump but in the ice drifting perspective it would be a compromise.

5.2 Geometry

The favorable geometrical form of the separate seawater intake would resemble an ice sea chest on a smaller scale, because ice sea chest geometry is designed so that it does not let ice get into the intake easily. But this is not always possible, due to space and location limitations that would come along when making the separate seawater intake resemble a small-scale ice sea chest. Making the separate seawater intake bigger in the sake of it not completely filling with ice slush and lessening the effects of negative pressure could be beneficial. The taller form would enable the ice to float up similarly as in ice sea chest. Having something similar to the weir wall would help guiding the ice pieces up instead of going to suction inlet. (Henriksson, R. interview 10.4.2024)

This is also a method of minimizing the risks in the phase of designing the newly built ship instead of an already existing ship. Making the design of the separate seawater intake more complicated comes that it would cost more and take the risk that it wouldn’t be working as desired.

5.2.1 Placement of the suction head

The placement of the suction head inside the separate seawater intake is one of the things that should be taken into consideration in the design process. With the right placement of the suction head the possibility of slush ice reaching up to the piping can be reduced. Inside the separate seawater intake, the ice tends to float up or follow the flow into the suction head. As the ice gathers up, the placement of the suction head at the top might not be the most optimal.

Placing it on the side of the chest could possibly separate ice from the flow of water and reduce the chance of ice getting sucked in from the top where it accumulates. By sizing the suction head diameter up, the flow speed would be lower so that the ice drifting in could be avoided. It could lessen the negative pressure as well, inside the piping. (Henriksson, R. interview 10.4.2024)

5.3 De-icing arrangement

De-icing arrangement is a construct that includes heating systems that either melt the accumulated ice or keep the intake in operational condition. Commonly used de-icing solutions in sea chests are return water circulation, steam injection, steam heat exchanger and heating coil.

In chapter 3.1 the principle of return water cycling was introduced as de-icing method in ice sea chests. This way of cycling the warmed-up water back to the sea chest from the main engines is a very energy efficient way to bring the heating to the sea chest. The warm return water comes as a by-product of the engine cooling and otherwise it would be dispensed into the sea. As it is a by-product of engine cooling, the water does not need to be separately heated. (Smirnov, L. interview 8.4.2024)

As it is already utilized in ice sea chests it could be implemented to the de-icing the separate seawater intake as well, although not always possible due to long distances. If the return water were to be used in de-icing both the ice sea chest and the separate seawater intake, the amount that the separate seawater intake would consume would be subtracted from the amount that the ice sea chest uses alone. The precondition is that both seawater inlets would function reliably. Later in this section of this thesis, is a calculation example of how much return water is needed for the cases introduced earlier.

In steam injection steam is injected to the separate seawater intake via pipe inside it. The injected steam will then heat up the water surrounding the injected steam. In interviews with experts, most of them agreed that steam injection is not an efficient way of de-icing in long term but can be used as quick heating method. It was said that I the steam injection is already in place it does no harm. (Smirnov, L. interview 8.4.2024)

Heat exchangers are devices that use source heat to transfer their energy to another medium using the heat exchanger device. In de-icing arrangements heat exchangers can use one of the heat sources from the ship such as steam or return water, to heat up the water in the separate sea water system. The heat exchanger can be in a separate location in which case the water from the separate se water intake is routed through it or it can be placed inside the separate sea water intake chest. Heat exchangers can be used to keep the seawater system operation ready indefinitely.

A heating coil is a tubular coil that is inserted into the separate sea water intake. Inside the coil circulates a warm substance, for example glycol water or steam. Then the warm substance in return heats up the water inside the separate seawater intake.

There is always limitation to what kind of de-icing methods are available to use, for example due to long distances in a ship, using the return water is difficult or impossible. The most advanced system would be a combination of two methods, for example a return water and heating coil to guarantee operational reliability. In the event where one of the de-icing systems broke down there is another one to take over.

5.4 Calculation of heating power requirement

The amount of heating power that is needed for melting the ice inside the separate seawater intake and raising the temperature of seawater over 0°C is calculated in this chapter. The calculations are made with the variables of mass flow, ice concentration, ice temperature and water temperature. In this calculation the water-ice mixture is treated as homogeneous, and the ice concentration is measured in percentages. When considering the ice percentage, it is important to keep in mind that the calculations are made using homogeneous mixture and not a varying amount of ice concentration that includes ice chunks and ice-free water mixed. These calculations are based on the two ship cases introduced earlier, but they are only used as an example for these calculations, and do not represent an actual situation.

These following equations calculate the theoretical amount of power that is needed to be put into the water-ice mixture to keep it unfrozen. This amount of power will need to be put into the water one way or another, meaning one needs to raise the temperature of the mixture up by heating it with something or by mixing it with another warmer substance. Afore said power input methods are discussed further and some calculations are to determine the feasibility of different methods of heating up the mixture.

The constants and variables needed for the calculation are as follow:

$$\dot{\text{m}} = mass\ flow\ [kg/h]$$

$$\text{C}_\text{i} = \text{specific heat capacity of ice } [\text{ J/kg } \times \text{°C }]$$

$$C_w = specific\ heat\ capacity\ of\ water\ [J/kg \times °C]$$

$$\rho_i = density\ of\ ice\ [\ kg/m^3\ ]$$

$$\rho_w = density\ of\ water\ [\ kg/m^3]$$

$$L = fusion\ heat\ of\ ice\ [J/g\ ]$$

$Q = heating\ energy\ [\ J\ ]$

$Q_p = heating\ power\ [\ kW\ ]$

$T1 = start\ temperature\ of\ ice\ [\ °C\ ]$

$T2 = start\ temperature\ of\ water\ [\ °C\ ]$

$T3 = desired\ temperature\ [\ °C\ ]$

$\sigma = consentration\ of\ ice\ in\ water\ \ [\ \%\ ]$

$\dot{V} = volumetric\ flow\ rate\ [\ m^3/h\ ]$

The base formula according to Tekniikan kaavasto (2020) goes as follows:

$$Q = m \times Cp \times \Delta T \qquad (1)$$

Which is modified in three stages of calculation. The outcome of this calculation is the energy in joules. In the first stage of the calculation, it is calculated how much energy is needed to get the ice heated to 0 °C. To get mass flow rate of the substrate the volumetric flowrate $\dot{V}$ is multiplied by the density of the flowing substrate ρ_i (ice) to acquire the mass flow rate $\dot{m}$. C is the specific heat capacity of the ice, which is constant. It is the amount of energy that is required to raise the temperature of 1 kg of ice by 1 °C. The ΔT is replaced by $(T3 - T1)$. It represents the start temperature and desired temperature and thus the change in temperature. σ is added as the ice concentration value. The outcome of this equation is in J/h, after it is modified to work with mass flow rate, rather than mass.

$$Q_{p1} = (\rho_i \times \dot{V}) \times C_i \times (T3 - T1) \times \sigma \qquad (2)$$

The second stage calculates how much energy is needed to transform ice into liquid form. The formula stays the same except for replacing $Cp_i \times (T3 - T1)$ with L, which stands for the fusion heat of ice. Fusion heat or enthalpy of fusion is constant. It represents the power needed to transform ice from the solid state to liquid water. Outcome of this calculation is also in J/h.

$$Q_{p2} = (\rho_i \times \dot{V}) \times L \times \sigma \qquad (3)$$

In the third stage, the formula for power needed to heat the water surrounding the ice is similar to the first stage. The constants ρ_i and C_i are changed to ρ_w and C_w, which are the density of water and specific heat capacity of water. The ice concentricity is subtracted from the formula with $(1 - \sigma)$. If the sum of this formula is negative it means that the water is adding power to the system, thus melting the ice.

$$Q_3 = (\rho_w \times \dot{V}) \times C_w \times (T3 - T2) \times (1 - \sigma) \qquad (4)$$

To get the total power requirement in joules per hour, all the calculations are summed:

$$Q_p = Q_{p1} + Q_{p2} + Q_{p3} \qquad (5)$$

5.4.1 Case 1 calculation

Using formulas given above as an example calculation can be done, purely to demonstrate how the formula can be used. First demonstration calculation done, uses values based in ship case one mainly the pump flow. In this example the ship was only given a general value that how much all the consumers consume if they very to be driven simultaneously. For this example, value of 45 m^3/h will be used to represent a single consumer, purely for demonstration purpose. Ice temperature was assumed to be at - 2 °C and water temperature at - 0.5 °C again as just an example. The openings of the intake in the bottom are 20 mm wide, which restricts ice size that gets in.

Ice concentration was estimated to be at 3 %, but it can vary a lot depending on the ice quality and compactness that the ship is sailing through. For this example, it is assumed that the ship is sailing through close drift ice. It is also assumed that most of the ice breaks in large pieces and only a small portion of it is smaller brash ice sized smaller than 20 mm. Also, a lot of the smaller brash ice goes around the intake opening altogether.

$$Ice\ temperature = -2\ [°C]$$

$$Water\ temperature = -0.5\ [°C]$$

$$Ice\ concetration = 3\ [\%\}\ (0.03)$$

$$Volumetric\ flow\ rate\ of\ pump = 45\ [m^3/h]$$

Calculating heating power required for ice:

$$Q_{p1} = 917\ kg/m^3 \times 45\ m^3/h \times 2090\ J/kg \times °C \times |\ 0 - 2\ | \times 0{,}03 \tag{6}$$

$$Q_{p1} = 5174631\ \ J/h$$

To get kilowatts from the joules per hour it needs to be divided by 3600000

$$\frac{5174631\ J/h}{3600000} = 1{,}4\ kW \tag{7}$$

Next the power requirement for melting the ice is calculated

$$Q_{p2} = 917\ kg/m^3 \times 45\ m^3/h \times 333000\ \ J/kg \times 0{,}03 \tag{8}$$

$$Q_{p2} = 410888700\ J/h$$

$$\frac{410888700\ J/h}{3600000} = 114{,}1\ kW \tag{9}$$

Next the power requirement for the water is calculated:

$$Q_{p3} = 997\ kg/m^3 \times 45\ m^3/h \times 4186\ J/kg \times {}^\circ C \times |\ 0 - 0{,}5\ | \times (1 - 0{,}03) \tag{10}$$

$$Q_{p3} = \ 9108537{,}2\ \mathrm{J/h}$$

$$\frac{9108537.2\ \mathrm{J/h}}{3600000} = 2{,}5\ \mathrm{kW} \tag{11}$$

To get the final power requirement all the result are combined:

$$Q_p = 1{,}4\ kW + 114{,}5\ kW + 2{,}5\ \mathrm{kW} \tag{12}$$

$$\underline{\underline{Q_p = 118{,}4\ kW}}$$

5.4.2 Case 2 calculation

Calculating the power requirement for ship case 2, the same calculations temperatures and ice concentration estimation is used as in ship case 1. Only value that changes is the volumetric flow rate of the pump which will be the given 70 m^3/h.

$$Ice\ temperature = -\ 2\ [{}^\circ C]$$

$$Water\ temperature = -\ 0{,}5\ [{}^\circ C]$$

$$Ice\ consetration = 3\ [\%]\ (0{,}03)$$

$$Volumetric\ flow\ rate\ of\ pump = 70\ [m^3/h]$$

Calculating heating power required for ice:

$$Q_{p1} = 917\ kg/m^3 \times 70\ m^3/kg \times 2090\ J/kg \times °C \times |\ 0 - 2\ | \times 0{,}03 \quad (13)$$

$$Q_{p1} = 8049426\ J/h$$

To get kilowatts from joules per hour it needs to be divided by 3600000

$$\frac{8049426\ J/h}{3600000} = 2{,}2\ kW \quad (14)$$

Next the power requirement for melting the ice is calculated

$$Q_{p2} = 917\ kg/m^3 \times 70\ m^3/kg \times 333000\ J/kg \times 0{,}03 \quad (15)$$

$$Q_{p2} = 641258100\ J/h$$

$$\frac{641258100\ J/h}{3600000} = 178{,}1\ kW \quad (16)$$

Next the power requirement for the water is calculated:

$$Q_{p3} = 997\ kg/m^3 \times 70\ m^3/h \times 4186\ J/kg \times °C \times |\ 0 - 0.5\ | \times (1 - 0{,}03) \quad (17)$$

$$Q_{p3} = 14168835{,}6\ \mathrm{J/h}$$

$$\frac{14168835{,}6\ \mathrm{J/h}}{3600000} = 3{,}9\ \mathrm{kW} \quad (18)$$

To get the final power requirement all the result are combined:

$$Q_p = 2{,}2\ kW + 178{,}1\ kW + 3{,}9\ \mathrm{kW} \quad (19)$$

$$\underline{\underline{Q_p = 184{,}2\ kW}}$$

From the results one can see that by far the biggest power consumer in these calculations was the power required to melt the ice. This might be due to the mild temperature differences chosen for the ice and water but nevertheless even at 3 % concentration power requirement for melting ice in both cases was over 100 kW. This could indicate that the percentage of ice chosen might still be unrealistic to represent a real situation. Or if a scenario were to happen where ship's separate seawater intake is sucking in 3 % ice concentration, it would require considerable amount of power to keep the separate seawater intake operational. To further calculate other scenarios possible, the calculations should be put to a format where many different scenarios can be compared simultaneously.

5.4.3 Excel sheet and line chart

The above calculations were put in to excel to compare different scenarios where ice concentration and pump flow rates along with temperature can be changed easily and their effect on power requirement can be seen visually in a line chart. Inputting values to the sheet, it calculates the power required to melt the fluid specified for it. The calculation is very rudimentary, so it only indicates a ballpark number that the melting power could be. Below is an example line chart from different ice concentration levels at different flow rates, to do some example comparisons. Each line reprecent a constant flow rate. On bottom-axis is ice concentration presented in fractions and on right-axis is required melting power. Higher the line goes the more power is required to melt the ice concentration in the water. And the further it goes to the right, the higher the ice concentration is.

Table 2. Excel table of power requirement calculation

Constants				
Density of ice [kg/m³]	Density of water [kg/m³]	Specific heat capacity of ice [J/kg*°C]	Specific heat capacity of water [J/kg*°C]	Fusion heat of ice [J/kg]
920	997	2090	4186	333000
Variables				
Ice temperature [°C]	Water temperature [°C]	T3, Desired temperature [°C]	ΔT1 Temperature change, ice [°C]	ΔT2 Temperature change, water [°C]
-2	-0,5	0	**2**	**0,5**
Case n.	Water consentration [%]	Ice consentration [delta c]	Flowrate [m³/h]	**Melting power [kW]**
1	100	0,00	15	**8,69**
2	99	0,01	15	**21,53**
3	98	0,02	15	**34,37**
4	97	0,03	15	**47,21**
5	96	0,04	15	**60,05**
6	95	0,05	15	**72,89**
7	94	0,06	15	**85,72**
8	93	0,07	15	**98,56**
9	92	0,08	15	**111,40**
10	91	0,09	15	**124,24**
11	90	0,10	15	**137,08**

On this chart the ice concentration is set to varying values whereas the flowrate is set to constant value. These can be switched so that the flowrate is varying, and the ice concentration is constant.

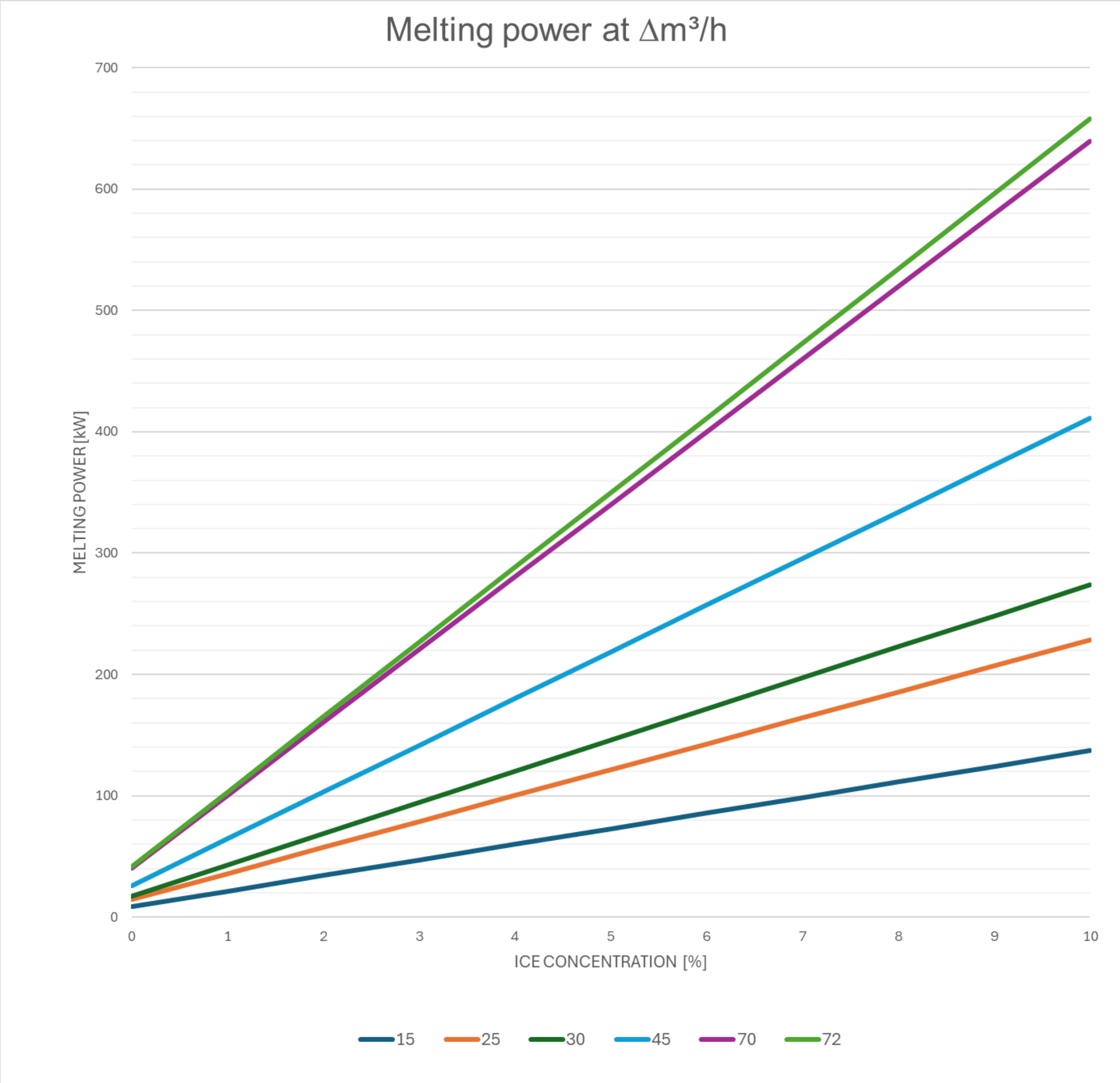


Figure 1. Line chart of pump flowrate.

When interpreting the graph one can see that at zero ice concentration all the lines are at a similar level, but as the ice concentration increases so does the difference between the power requirements. At around 70-72 m³/h pump flow the ice concentration only needs to be around 1 % to require 100 kW of power to melt it. When the pump flow is 15 m³/h ice concentration can be over 7 % to require the same 100 kW of power. The pump flows were chosen based on the cases presented before in this thesis and some flowrates were added from below the flowrates of the cases. One exception is the flow rate of 72 m³/h, which represents the required flow rate for the emergency fire pump as specified by SOLAS Regulation 5 chapter (a)-ii:

"*In a cargo ship, the required fire pumps, other than the emergency pump (if any), shall be capable of delivering for fire-fighting purposes a quantity of water, at the appropriate pressure prescribed, not less than four-thirds of the quantity required under Regulation 18 of Chapter II-1 to be dealt with by each of the independent bilge pumps in a passenger ship of the same dimensions when employed on bilge pumping, provided that in no cargo ship need the total required capacity of the fire pumps exceed 180 cubic metres per hour*."

5.4.4 Case 1: Heat exchanger calculation example

Since the ship in case 1 uses box coolers for the engine cooling, the return water cannot be used in de-icing. The reason for this is the closed system that box coolers use for engine cooling, meaning that the system does not take cooling water from the sea or return it back to it. For this case a heat exchanger is used instead to calculate theoretical power need as an example. Due to the complex nature of heat exchangers, their calculations and lack of known variables, the following calculations are very rough estimates and for demonstration purposes only.

With the following calculations, it will be calculated how hot substance should be used in a 300 m^2 heat transfer area heat exchanger. The substance that will be used to heat the water is not known, but for this calculation a general estimate of overall heat transfer rate of 2000 W/m^2 will be used. It is assumed that the outlet temperature of the heating substance is 90 °C, meaning that when it comes out of the heat exchanger its temperature will be 90 °C. In this calculation the energy required for the heating of the separate seawater intake is estimated using excel to be around 29160000 Joules. The required return temperature was calculated to be 18 °C using excel when the inlet temperature was at - 1 °C.

The formula used to calculate inlet temperature of the heating substance as specified by Tekniikan kaavasto (2020) is as follows:

$$Q = U \times A \times \Delta T_m \tag{20}$$

Where:

$$Q = Heat\ transfer\ rate\ [kW]$$

$$U = Overall\ heat\ transfer\ coefficient\ [\ kJ/h\ \times m^2 \times {}^\circ C]$$

$$A = Heat\ transfer\ area\ [m^2]$$

$$\Delta T_m = Log\ mean\ temperature\ difference\ [{}^\circ C]$$

To be useful for calculating inlet temperature of the heating water, the formula needs to be modified by expanding the Log mean temperature difference formula.

$$Q = U \times A \times \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} \tag{21}$$

Where:

$$T_1 = Inlet\ temperature\ of\ heating\ substance$$

$$t_1 = Inlet\ temperature\ from\ separate\ seawater\ intake$$

$$T_2 = Return\ temperature\ of\ heating\ substance$$

$$t_2 = Return\ temperature\ to\ separate\ seawater\ intake$$

Now the formula can be used with the variables known, to calculate the required heating substance temperature:

$$8.1\ kW = 300\ m^2 \times 2000\ kJ/h \times m^2 \times °C \times \frac{(T_1 - 18\ °C) - |\ 90\ °C - 0,5\ °C\ |}{\ln \frac{(T_1 - 18\ °C)}{|\ 90\ °C - 0,5\ °C\ |}} \quad (22)$$

Solving for T_1 gives answer = $108,5\ °C$

As stated above, this calculation is only a very rough estimate and does not compare to any given real-world application.

5.4.5 Case 2: Return water calculation example

In chapter 5.3 the power requirement was calculated to keep the separate sea water intake unfrozen. In this chapter those calculations will be expanded upon to study the water flow needed and the temperature of the water needed to meet the power requirements. Using Chapter 5.3 calculation formulas at 3 % ice concentration and at 70 m³/h flow rate following result is given.

$$Q_p = 2,2\ kW + 178,1\ kW + 3,9\ \mathrm{kW} \quad (23)$$

$$Q_p = 184,2\ kW$$

Using the power requirement value, the need for return water flow can be calculated if the temperature of the return water is known. For this example, a temperature of 40 °C will be used. To calculate the required volume flow of water, it is needed to calculate how many degrees could the required power amount heat up 70 m³/h of water. To do this the same formula will be used that was used in chapter 5.3:

$$Q_p = \rho \times \dot{V} \times C \times \Delta T \quad (24)$$

It will be modified so that the result is the temperature rather that power:

$$\Delta T = \frac{Q_p}{C \times \dot{V} \times \rho} \tag{25}$$

Using this formula, we can calculate how much the temperature of the water would increase with the given power:

$$\Delta T = \frac{661352127{,}59\, J/h}{4186\, J/kg \times 70\, m^3/h \times 997\, kg/m^3} \tag{26}$$

$$\Delta T = 2{,}26\, °C$$

Now that the temperature increase is known, required amount of 40 C° water can be calculated using following formula:

$$T = \frac{\rho \times \dot{V}_1 \times t1 + \rho \times \dot{V}_2 \times t2}{\rho \times \dot{V}_1 + \rho \times \dot{V}_2} \tag{27}$$

Modified to solve for $\dot{V}_2$:

$$\dot{V}_2 = \frac{\left(\dot{V}_1 \times \rho \times (T - t1)\right)}{\dot{V}_1 \times (t2 - T)} \tag{28}$$

Inserting values defined earlier:

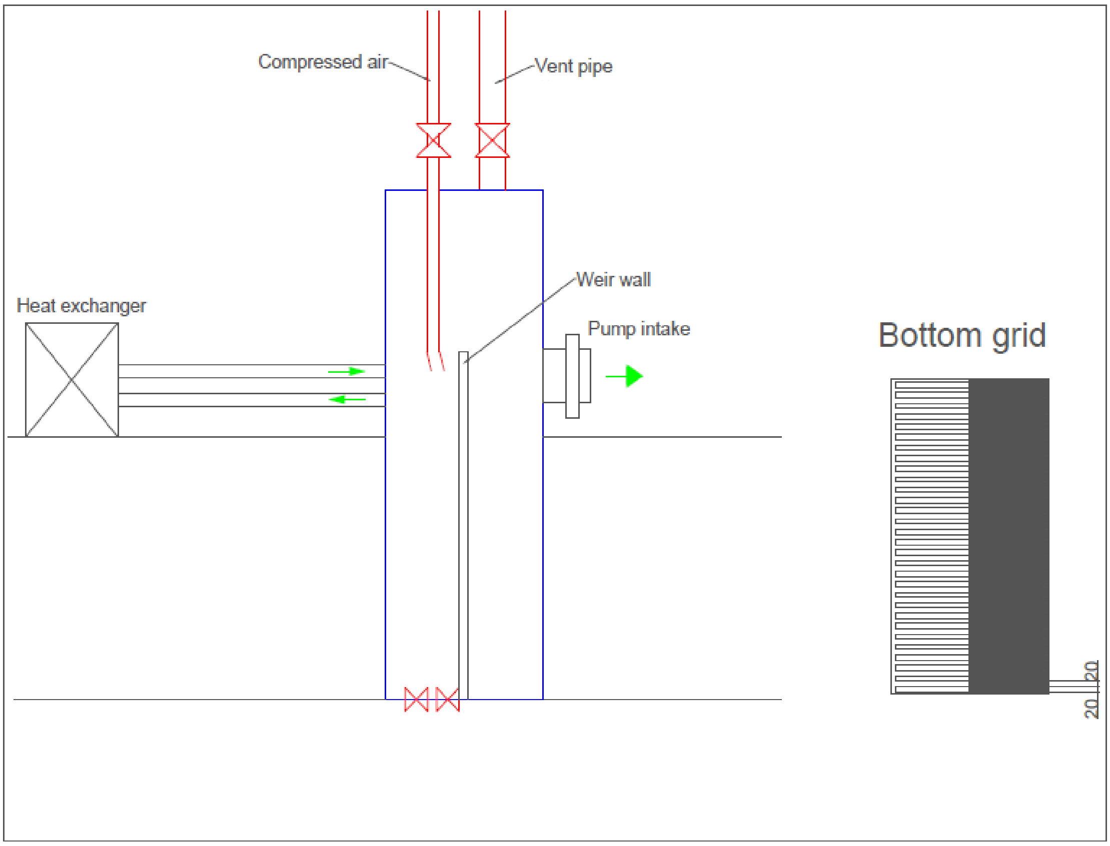
$$\dot{V}_2 = \frac{70\, m^3/h \times 997\, kg/m^3 \times |\, 2{,}26381\, °C - 0{,}5\, °C\, |}{70\, m^3/h \times (40\, °C - 2{,}26381\, °C)} \tag{29}$$

$$\underline{\underline{\dot{V}_2 = 73\, m^3/h}}$$

With this result we can determine that when ice concentration of 3 % is sucked into the separate sea water intake at 70 m³/h, it needs to be mixed with 73 m³/h of 40 °C water to keep it operational. Real results might vary from this result, since this is calculated with rough estimates.

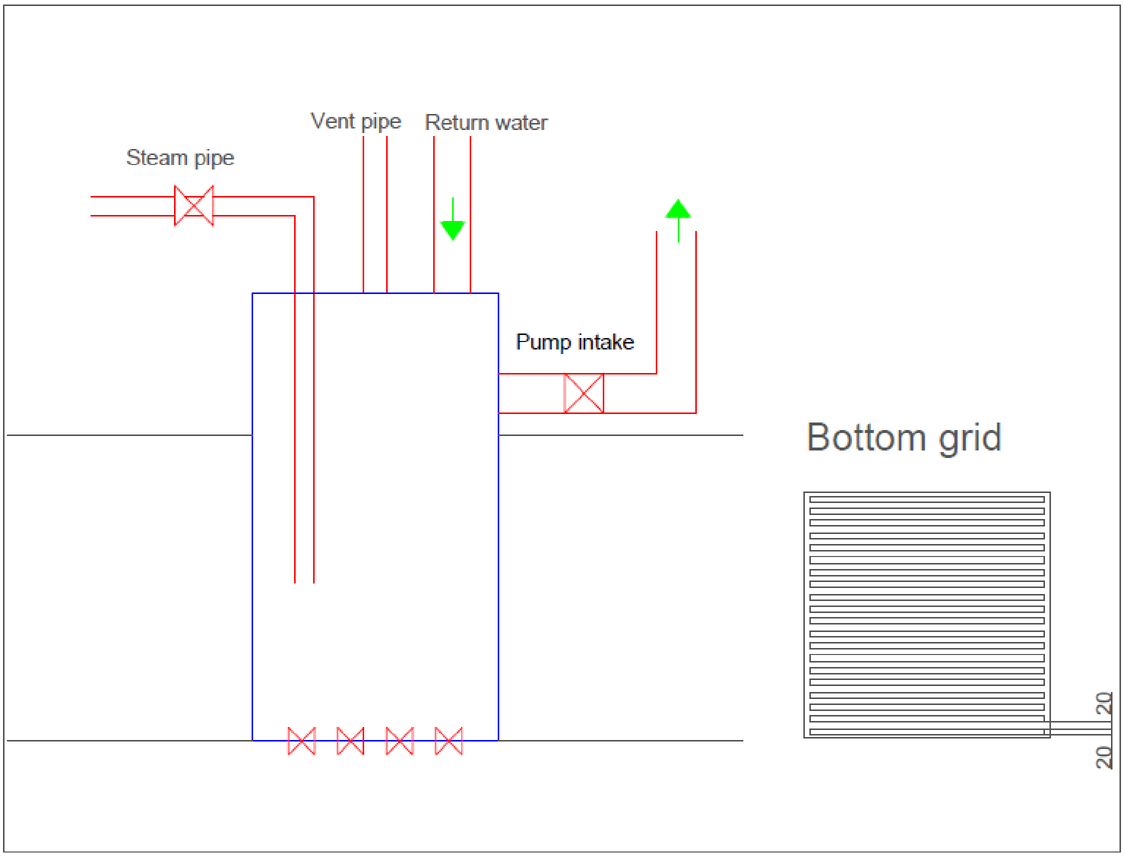
5.5 Suggestions to the designs and de-icing arrangements

In this chapter the way that the previously mentioned improvements could be implemented in the ship cases is demonstrated with after-pictures. These are just based on ideas that have come up with interviews and do not represent an actual blueprint. To make sure that the designs work properly further testing would be needed.



Picture 10. Case 1 suggestions

With the first case the geometry is modified by making it taller and adding a weir plate to guide the water flow. The bottom opening is split into half to help the weir plate to function. Heat exchanger is added as a de-icing arrangement. In this demonstration the heating substance inside the heat exchanger is not fixed but steam would be an option available. This design resembles an ice sea chest in a smaller scale.



Picture 11. Case 2 suggestions

In case 2 the height is increased, and the placement of the pump intake is shifted to the side. Return water is added to the top and it faces the pump intake so that the warm water would help to keep the suction head unfrozen.

The changes to the designs are thought to be small enough to be realistically doable and don’t interfere with the original design, but they do not consider the ships design and space limitations that they were in.

5.6 Automation

When going further into the designing process, automation could be implied to ensure the operational reliability of the separate seawater intake. Automation would help prevent unwanted situations in advance. In one of the interviews, it was said that the automation would be fairly easy to construct. (Henriksson, R.

interview 10.4.2024) By utilizing automation technology, the state of the separate seawater intake could be under control since the problems cannot most likely be completely avoided.

5.6.1 Electronics and sensor technology

Sensor technology can be used to get important measures of the state of the separate seawater intake from critical points. Mostly the system sensors would consist of temperature and pressure sensors meant for the seawater circulation. Temperature sensors would be needed for monitoring the water temperature of water inside the chest, intake pipe and return water from engine. Pressure sensors might only be needed in the inlet pipe area to monitor pressure fluctuations inside the intake pipe. Using the data from the sensors and a PLC (Programmable Logic Controller), it is possible to construct a closed loop system that can control de-icing and heating systems effectively.

5.6.2 Monitoring and data logging the ice quality and concentration

Monitoring and datalogging would help to gather data about the circumstances where problems arise. It could create an overall picture including the ice quality and concentration, ship’s sailing speed, information from the sensors, pump speed and the de-icing requirement. The season and the location of the ship would be also valuable information. Data logging the information would benefit future research, product development and possible simulation models. Wider research would benefit the overall knowledge of seawater systems in active use on a variety of vessel types.

6 Conclusions

The purpose of this thesis was to study the separate seawater system and problems that they have had and to study and introduce possible solutions for these problems. Gathering information from internet sources was difficult due to lack of specific information, therefore interviews were conducted with experts in this field. Interviews brought up a lot of important information for the thesis and a lot was also left out due to time constraints. The interviewees from different companies had a lot of different answers on the same questions, but also a lot of the same experiences from separate seawater intakes getting clogged. The interviewees all agreed that ice concentration and quality had a considerable effect on the functionality of the separate sea water intake. All the interviewees were also in consensus of the return water being the most promising de-icing method. It was also a common opinion, that it is not possible to prevent the separate sea water intake from filling up with ice, but it can be held under control to degree.

Two of the most considerable solutions for preventing ice clogging the separate seawater intake were preventing ice from getting into the intake as much as possible and melting the ice that gets to the intake with return water. After studying the de-icing solutions and making example calculations it became clear that even 10 % ice concentration in the seawater requires a considerable amount of energy to melt it. This brought up a point that what kind of ice concentration do separate seawater intakes deal with?

When estimating ice concentration, there are countless different scenarios and variables to consider. It is almost impossible to determine ice concentration even if a sample is gotten from the seawater that the ship is sailing through. The reason for this is that the underside of ship is very chaotic and turbulent place and the ice amount that gets sucked in rarely can stay constant unless the water is nearly homogeneous. One way to have a rough estimate of the possible ice concentration is to analyze the compactness of the ice field that the ship is sailing through. The brash ice amount that comes from a certain compactness of an ice field could be estimated with scale simulations. Studying ice concentration with data from the separate seawater intake and ice quality that the ship is sailing though could give valuable information for the future designers of the separate seawater system and later for the crew of the ship to predict the possibility of problems in the separate seawater intake. After doing the calculations and thinking of de-icing methods a conclusion was made that reducing the ice concentration that goes to the intake even by couple of percent would make de-icing the separate seawater intake a lot more plausible.

For future improvement some basic design principle should be implemented along with some kind of database from previous problems and designs and their problems. Simulations and real-world data should also be gathered from the environment inside the separate seawater intake and the surrounding environment the ship is sailing through.

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