ISOPE Proceedings — Experimental investigation of deicing with seawater

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ABSTRACT

Increased traffic and interest in arctic regions necessitate measures to ensure the safety and functionality of vessels. Sea-spray icing is one of the significant hazards for small- and medium-sized vessels in polar waters. Ice cover can restrict access to essential parts of a vessel and compromise its stability. Existing deicing measures, such as heat or chemical application and manual ice removal, prove impractical in many cases. Seawater, being abundant and easily accessible during marine operations, has a good potential as a deicing agent, as shown by wave-washing. The present study assesses seawater deicing through a full-scale experiment on a lifeboat docked in a harbor in Northern Norway, with ambient air and seawater temperatures of -8 °C and 3 °C, respectively. A 10-20 mm thick ice layer was created on the boat prior to the experiment. Deicing was performed using the fire protection system on the boat, capable of spraying water on the surface, fed by the ambient seawater and driven by the boat engine. After the 32-minutes experiment a significant part of the ice was melted or washed away, thereby restoring functionality and access to the windows, hatches, lifting hooks and railings. The method was more efficient on the vertical surfaces than on the horizontal ones. Some improvements in the sprinkler system layout and design may enhance the performance of the method.

KEY WORDS: Deicing; full-scale testing; arctic engineering; sea-spray icing.

INTRODUCTION

There has recently been an increase in offshore oil and gas activity in the far north, and it is expected to rise further in the arctic regions. There has also been a substantial increase in tourism, like cruises to Svalbard. The decline of Arctic sea-ice is expected to lead to shorter trade routes through the Arctic. Operations in the Arctic are challenging due to the harsh weather conditions. Ice accretion on vessels can cause blockage of critical systems like the ventilation system and escape doors and cause hazardous working conditions on board due to slippery decks. In extreme situations, a lopsided ice load may lead to capsizing in the case of smaller vessels (Deshpande et al., 2021). Literature provides some studies on medium-sized fishing vessels and offshore platforms (Kulyakhtin & Tsarau, 2014; Ryerson, 1995; Samuelsen et al., 2017; Zakrzewski, 1986). However, there has been little focus on icing-related problems on smaller boats, especially on safety boats onboard cruises, other vessels, and on offshore platforms. These safety boats are usually general purpose built and mandated as per the SOLAS convention (International Maritime Organization (IMO), 1974), and not constructed specifically for cold climate conditions. The Polar Code (International Maritime Organization, 2016) refers to winterization measures for ships sailing in arctic waters but does not specifically focus on the safety boats onboard these ships.

Sea-spray icing is the most severe form of marine icing, accounting for over 80-90% of reported severe offshore icing incidents (Kulyakhtin, 2014). Favorable ship design, covering of open deck solution, heating and manual ice removal are the most common anti-icing and deicing methods. Heating to prevent and remove ice on vessels is energy-intensive and normally reserved for high-priority locations like wheelhouse windows, topside equipment, rails, doors, hatches, etc. The use of chemicals for anti & deicing purposes has health and environmental aspects and is simply not practical for most cases. In general, there is a lack of applicable and sustainable methods for anti-icing and deicing for vessels operating in cold and arctic waters. Manual deicing of deck and superstructure on traffic and fishing vessels is often the only applied option.

Sea-spray icing

In general, the development of sea-spray icing depends on a rather complex correlation between metocean parameters and vessel characteristics. The governing metocean parameters are wind speed, air temperature, water temperature, freezing temperature of water and wave characteristics. Vessel characteristics include effects from ship design and ship maneuvering. Sea-spray icing may occur when shipped water or deposited spray on the vessel surface is being cooled below the freezing point. This requires that the air temperature lower than the freezing point of seawater. In open waters, the ocean water salinity is, on average, about 35 psu, corresponding to a freezing temperature of -1.9°C (ISO, 2019). Corresponding winter water temperatures are typically down to 3°C.

Sea-spray icing normally occurs as a result of regular and frequent sea sprays on the vessel, just enough for the seawater to freeze on the surfaces between the impacts. Since the seawater during icing events is warmer than the air, increasing the frequency and flux of incoming spray will at some point be sufficient to avoid freezing and contribute to melting and flushing away the existing ice on the vessel (ISO, 2019). During extreme winds and waves, dense sea spray and shipped water will prevent sea spray icing on the vessel. As a result, deliberate ship maneuvers may be applied to increase spray flux and shipped water to remove ice. This may be a hazardous action, but it shows a potential for using seawater for deicing purposes. With its thermal capacity, seawater may be considered an infinite and sustainable resource for deicing at sea.

Deicing by applying seawater

The main objective of the experiment was to investigate the effect of using the existing fire sprinkling system with seawater to deice the topside of a Miriam 8.5 lifeboat. In principle, this would only work if the flux of the sprinkling seawater is large enough for the latent heat of this water to avoid freezing and further contribute to the melting and flushing away of ice that has formed on the vessel. The distribution of seawater across the lifeboat topside needed for fire protection should not be far from the distribution needed for deicing purposes. Also, the seawater spray and dispersion from the sprinkler nozzles provides a certain mechanical flushing effect. The topside of closed lifeboats is generally a convex structure with a minimum of equipment and no railings to hold back the melting ice, which should make this a feasible task. The challenge is, however, to create a favorable distribution of flushing seawater over the topside and being able to deice the vessel in a reasonable time. The success factor depends on whether the priority locations as the steering tower windows, hatches & doors, towing hook/painter connection etc. is sufficiently cleared from ice and the overall reduction of topside ice thickness. Also, the nozzles must not re-freeze and be clogged after deicing.

It has long been known that increasing sea-spray flux or flushing of seawater eventually may melt away ice formed by sea-spray. The method of applying the sprinkler system for deicing purposes was successfully tested by P.A. Sundsbø in 2018 on a FF1200 lifeboat equipped for the Goliat field in the Barents Sea. The main objective of this experiment was to investigate the effect of using the existing fire sprinkling system with seawater to deice the topside of a Miriam 8.5 lifeboat. The findings of this experiment could be a basis for further development of procedures for deicing of lifeboats, to develop methods for deicing of ships and marine structures in general and to serve as input for the Polar Code.

TEST OF SEAWATER DEICING

The seawater deicing test was performed on a small vessel, a Viking Norsafe Miriam 8.5 lifeboat with a capacity for 55 passengers, on the 6th of January 2023. The fire sprinkler system is designed to cover and flush the entire surface of the lifeboat with a film or layer of seawater when the boat is waterborne. A self-priming sprinkler pump located directly on the main ship diesel engine provides sea water through the boat internal piping to a manifold mounted externally on the canopy. The water is then distributed through sprinkler rails which are fitted with spray nozzles that disperse the seawater from the top of the steering tower and lifeboat canopy, see Fig. 1. The downward and upward blue arrows on the sprinkler pipes in Fig. 1 mark the position of the sprinkle nozzles facing to and from the observer, respectively. Fig. 2 and Fig. 3 show the lifeboat before the deicing procedure.

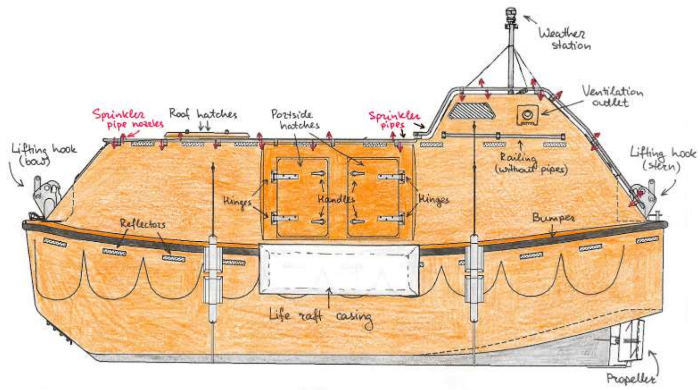

Fig. 1 External general arrangement of the Miriam 8.5 lifeboat from Viking Norsafe.

Fig. 2 Ice applied on the portside of the lifeboat.

Fig. 3 Ice applied on the starboard side and stern.

Instrumentation and setup

The test location in Narvik Marina provided a safe and convenient work environment with favorable weather conditions. The ambient air temperature was logged with a thermometer positioned outside the spray zone and approximately 0.5 meters above the sea surface. Wind speed and sea state were observed visually. Seawater temperature was measured with a temperature probe prior to and after the deicing procedure. Samples of seawater were collected and measured with a salinity meter. All instrument specifications, operating ranges and accuracy are detailed in Table 1.

Prior to deicing, the ice-cover on the boat was mapped by manually measuring ice thickness at selected locations with a caliper through predrilled holes in the ice cover, see Fig. 5 and Fig. 6. The experiment and measurements were documented with video and photos by multiple GoPro cameras.

The fire sprinkler system was operated from inside the boat, with seawater being pumped directly from the sea and sprayed from the nozzles of the distribution system. The flow rate from the sprinkler system was directly controlled by the effect of the engine. A regiment of time intervals was preset for the sprinkling flux rate; 10 minutes at 50 % capacity followed by 10 minutes at 75 % capacity. After a small break, an additional deicing period was added with 10 minutes at 75 % engine capacity. The test setup was chosen from experience with corresponding deicing test. After testing, the system/pump were drained to prevent seawater from freezing inside.

Table 1 Measuring equipment

Equipment	Specification	Comment
Salinity meter	Hanna HI98192 USP compliant EC, TDS, NACL, Resistivity Temperature meter, with electrode: HI763133.	Range TDS 0.00 to 400 g/L. Accuracy ± 1% of reading.
Thermometer	Fluke 54 II B thermometer	
Air probe for Fluke	Fluke 80PK-26 SureGrip Tapered Temperature Probe	Accuracy ± 2.2°C, range -40°C to 293°C
Water probe for Fluke	Fluke 80PK-25 SureGrip Piercing Temperature Probe	Accuracy ± 1.1°C, range 0°C to 350°C

Ice build-up, distribution and properties

Prior to the sprinkler deicing test, a layer of ice was created on the lifeboat topside. Existing snow and ice were removed from the boat, and a hose was used to spray and disperse seawater across the lifeboat. The hose nozzle was used at a wide spread setting and arched towards the boat from a distance to ensure that the droplets were small enough. The seawater was pumped directly from the sea near the boat.

Most of the spray was applied on the port side and on the roof. From the 4th to the 6th of January in Narvik, there was no observations of snow or rain, and air temperatures ranged between -5 and -11 °C, and wind speeds were below 2 m/s, according to the Norwegian meteorological institute (Yr.no, 2023).

Fig. 4 Details from portside ice cover prior to test.

As visually observed, spraying of seawater resulted in quasi-even icing on the top part of the boat side, above the bumper, and on the roof. At a close look, the ice had a rough, uneven surface, and trapped air bubbles resulted in non-transparent patches, see Fig. 4.

Ice thickness on the port side and the boat's roof is graphically depicted in Fig. 5 and Fig. 6, respectively, where the locations of the circles correspond to the measurement points, and their color and annotations reflect the measured values in centimeters. On the side of the boat, ice thickness was nearly uniform in the range between 6 and 18 mm, with an average of 11 mm and slightly higher values in the top row of the front part and between the hatches. The highest thickness was measured at the bottom between the hatches, likely due to ice accumulation near the chain holding the life raft casing. On the roof ice thickness was higher than on the wall, with an average of 13 mm, and featured a pronounced difference between the port side (values up to 21 mm) and starboard side (5-10 mm). This gradient is caused by applying spay from the port side, with only a small number of droplets reaching the other side. Both the four bridge windows and the four windows had a relatively thin ice layer between 5 and 9 mm. Ice cover on the starboard side of the boat, due to the absence of direct spray, was too thin to be measured with precision.

An outcome of this manual icing procedure to simulate the ice buildup is that the accreted ice could have a different consistency/density as compared to ice accreted naturally due to sea spray. Brine pockets are formed in newly deposited ice, making the ice soft (Makkonen, 1987). After the manual icing procedure, the ice was allowed to rest for a day in similar negative temperatures. This led to hardening of the accreted ice as complete freezing of the brine pockets would have taken place. The results could be expected to show some amount of variation in case the deicing procedure was carried out on freshly deposited ice.

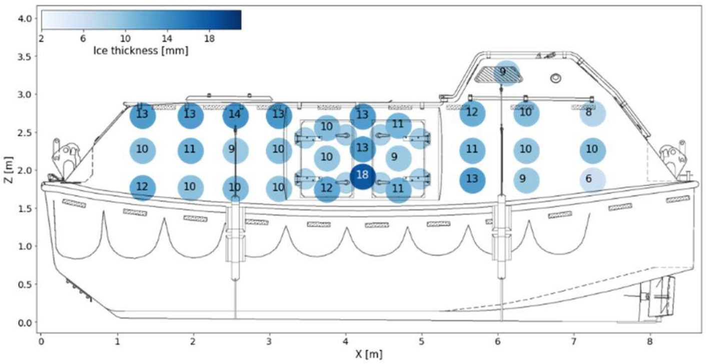

Fig. 5 Measured ice thickness on the portside.

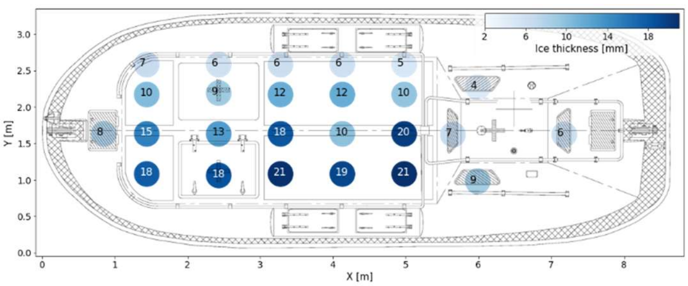

Fig. 6 Measured ice thickness on the roof.

Seawater salinity was measured at 34.2 psu, close to the average value for open ocean (Jain, 2011).

Ice collected from various locations on the lifeboat before the deicing test revealed a salinity of 18.2 psu, corresponding to newly formed sea ice (Cox & Weeks, 1974). The salinity of the ice cover is expected to decrease with time, with the brine draining down under the gravity force. Ice salinity distribution on the boat might have been uneven, e.g., higher salt content on horizontal surfaces and tips of icicles, but such distribution is outside of the scope of this study and was not assessed.

RESULTS AND DISCUSSION

The sprinkling deicing test was performed in Narvik harbor during metocean conditions favorable for sea spray icing to occur and during environmental conditions that at some point will be found in the northern Norwegian waters and in the Barents Sea. Deicing was carried out 24 hours after the last icing session. Weather conditions during testing were stable and calm, with neither wind nor waves, and ambient air temperature fluctuated between -10 and -8.3 °C. Due to the polar nights in North Norway, the boat was not at any time exposed to direct sunlight. Seawater temperature was measured before and after the test at 3.5 °C and 3.0 °C, respectively.

Deicing

A major portion of the ice layer on the lifeboat topside was removed during the deicing procedure. Ice was removed from priority locations such as windows and air inlet. The fire extinguisher system was run for a total of 31 minutes and 53 seconds during the test. The runtime was divided into 12 minutes, where the engine operated at 50 % capacity, and 20 minutes, where the system was run at 75 % capacity. Fig. 7 and Fig. 8 show the remaining ice on the vessel.

Fig. 7 Portside after the deicing procedure.

Fig. 8 Starboard and stern after the deicing procedure.

Fig. 9 illustrates the deicing progression and shows de-iced areas with five-minute increments from dark to light color. The remaining 2 minutes of runtime were added to the last timestep. Areas in direct contact with spray from the nozzles were generally deiced within five minutes (dark blue). Some locations with nozzles located above did not melt at the same phase. This could be caused by the fact that the initial ice thickness was greater or by blockages. Blockages could not be detected from videos. The relatively quick local deicing could be designed to target priority areas. The ice layer removed from the vessel had settled for approximately 24 hours. During a voyage under icing conditions, it is reasonable to expect an earlier deicing effort. Newly formed ice requires less energy to remove, and the amount of remaining ice after deicing would be lower.

The deicing rate depends on several factors, i.e., the water flux, nozzle design, and nozzle distribution.

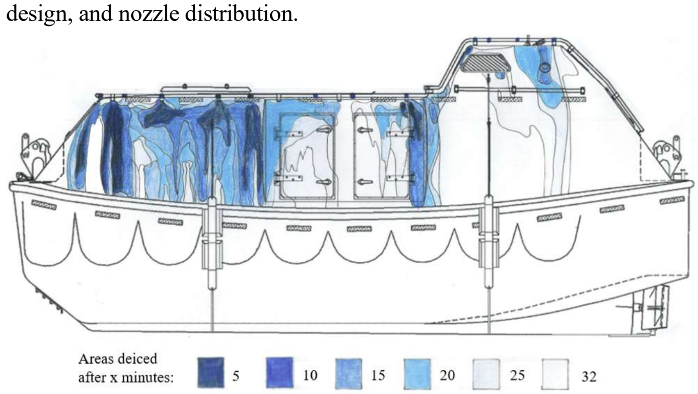

Fig. 9 Deiced areas in time intervals from dark to light color, i.e., the darkest patches correspond to the areas deiced in the first 5 minutes of

the test.

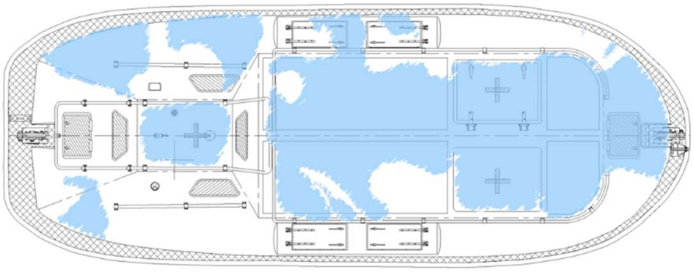

Fig. 10 Ice remaining on the roof after the deicing procedure (in blue).

High-priority locations such as windows and air inlets were successfully deiced during the procedure, see Fig. 11 and Fig. 12. Some ice remained on the escape hatches, but the soft ice could be easily removed, and the opening function of the doors and hatches was maintained. In general, the remaining ice on the lifeboat topside had a reduced thickness and was easy to remove manually, and sprinkling could be combined with other deicing efforts. However, the time spent deicing indicates that an upper limit of the ice layer thickness exists, above which the method is not practical. Topside equipment near the front towing hook/painter connection, was not sufficiently deiced, i.e., the attachment point for the tow rope.

Fig. 11 Steering tower with the windows and the air inlet (on the right) before deicing.

Fig. 12 Steering tower with the windows and the air inlet (on the right) after deicing.

Effects of surface design, topside equipment, and material properties on deicing

The ship geometry affected ice accumulation. On the vertical surface, an increased ice thickness was, for instance, found between the escape hatches. And the greatest ice thickness on the side of the boat was measured above an installation where run-off was restricted. The increases in thickness increased the time spent to deice.

On the horizontal surfaces, such as the roof of the lifeboat, the initial ice thickness was approximately 6 - 21 mm, and most of the top was not deiced after the exercise. Several factors caused the remaining ice thickness, in addition to the thicker initial ice layer. Fire rails were located at the side of the roof and not across the center, and fewer nozzles were directed toward the top compared to the side areas. The ice on the sides of the boat was melted by run-off from the roof, in addition to nozzles directed at the side surface. The ice accumulated on the vessel's sides could be removed in larger pieces by gravity, in contrast to the areas on the top where the ice needed to melt before running off the sides. One concern with ice on ships is the overall stability and weight of the ice. Even if the roof was not fully deiced, the overall weight on the top was reduced as the ice thickness was diminished.

Heat transfer by conduction contributed to the deicing of the pipelines. The distribution channels for seawater, with its beneficial thermal properties, could be incorporated into ship design.

The glass-reinforced plastic on the roof has an anti-slip finish in contrast to the polished and smooth surface of the remaining exterior. The increased surface roughness could have impacted the ice accumulation and deicing properties.

Nozzle design

The nozzle design influences functionality when the vessel is exposed to sea spray icing. The fire system on the lifeboat is pipelines where holes allow water spray to exit. The water is reflected towards the vessel's surface by a metal sheet. The metal sheet largely protected the pipeline from clogging during icing. Seawater spray was applied manually, and another direction of oncoming spray could have been less favorable for this design, e.g., spray coming upwards from the sea. The design should be tested during icing from sea-spray in natural conditions. Clogged fire sprinklers might result in a fire hazard.

Fig. 13 Sprinkler nozzle with and without ice.

Deicing procedure and cautions

The run-off during the exercise drained from the ship without issues. The pathways and potential build-up of run-off should be evaluated before applying a similar method. In addition, caution should be taken to open all hatches and doors after deicing to prevent the effects of the freezing run-off.

Ice accumulation during deicing. Fig. 14 shows the weather station mounted on the roof of the lifeboat before (upper left) and after (lower right) the deicing procedure. Droplets of the deicing spray reached the weather station and caused icing. Deicing can cause ice accumulation in adjacent areas where the water flux is low.


Fig. 14 Weather station mounted on the steering tower before (left) and after (right) the deicing procedure.

CONCLUSIONS AND RECOMMENDATIONS

The present study shows that a lifeboat sprinkler system could be applied for deicing of the lifeboat surface and topside equipment under certain conditions. With the initial ice thickness of 10-20 mm, running the deicing system for about 32 minutes achieved a partial removal of the ice cover, thereby restoring the functionality of high-priority areas, such as hatches, windows, hooks and railings.

The method proved more efficient on vertical and inclined surfaces, where the run-off of the flushing seawater was less restricted and therefore allowed for faster heat transfer as well as mechanical removal of ice. The knowledge obtained is transferable to other vessels and conditions, and the method is applicable where the run-off is controlled, i.e., on convex surfaces such as the lifeboat. However, individual design evaluations are required to implement the method. Locating nozzles strategically to optimize the effect of the run-off, as well as targeting high-priority areas with direct spray, would make the method more effective. Similarly, preparing for utilizing seawater to deice during the planning of surface design with computational fluid dynamics could optimize the pathways for run-off even further.

The time spent deicing a couple of centimeters thick ice layer indicates a limit to how thick ice it is practical to deice using lifeboat sprinklers. Preemptively deicing thin layers of ice is therefore preferable. Deicing intervals should be incorporated into procedures when traveling in weather conditions with the risk of sea-spray icing to limit ice accumulation.

Further investigations on the topic may include the following:

- Tests performed under different metocean conditions (e.g., wind, air and sea temperature).
- Determining possible risk factors related to conditions where sprinkling might increase the ice accumulation, freeze opening functions, clog air inlets etc.
- Removal of freshly accumulated ice created naturally by sea-spray.
- Tests of deicing intervals.
- Tests of various vessel designs.
- Testing alternative seawater distribution solutions.
- Optimizing the deicing of surfaces with computational fluid dynamics.

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