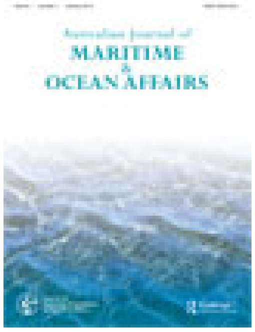

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Investigating the Polar Code's function-based requirements for life-saving appliances and arrangements, and the performance of survival equipment in cold climate conditions – test of SOLAS approved desalting apparatus at low temperatures

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ABSTRACT

As the sea ice extent steadily decreases, the Arctic region is simultaneously experiencing extensive growth in commercial shipping activities, in areas which previously were considered inaccessible for most ships during large periods of the year, increasing the probability of accidents or incidents occurring. *The International Code for Ships Operating in Polar Waters (The Polar Code)* states that resources shall be provided to support survival following abandoning a ship; desalting apparatus is proposed for the provision of the recommended amount of freshwater. However, previous studies have shown that the expected performance criteria for survival equipment are significantly reduced in cold climate conditions. In this paper, we present and discuss the results of testing SOLAS approved desalting apparatus at low temperatures in a controlled and enclosed environment, studying the equipment's performance capabilities.

KEYWORDS

The Polar Code; cold climate operations; function-based requirements; performance criteria; SOLAS approved life-saving appliances and arrangements; desalting apparatus

Introduction

The Arctic region has experienced extensive growth in commercial shipping activities, while, simultaneously, the sea ice extent is steadily decreasing, enabling extended seasons and voyages in areas previously considered inaccessible for most ships during large periods of the year (Protection of the Arctic Marine Environment [PAME] 2020; Silber and Adams 2019). The total increase in ship traffic experienced in the Arctic region, driven by fisheries, shipping and tourism (Protection of the Arctic Marine Environment [PAME] 2020), substantiates the probability of accidents or incidents occurring and puts pressure on the requirements for emergency response, dependent on limited resources covering vast areas (Hill, LaNore, and Véronneau 2015). *The International Code for Ships Operating in Polar Waters (The Polar Code)* was adopted in 2017 by the International Maritime Organization (IMO) and is applicable to the Arctic and Antarctic Oceans

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(International Maritime Organization [IMO] 2017). The Polar Code supplements existing IMO instruments, in order to increase the safety of ships' operations, and mitigates the impact on the people and environment in the remote, vulnerable and potentially harsh polar waters (ibid.). Mass tourism and the presence of large cruise ships operating in remote areas in the Arctic region represent the main concern (Solberg and Gudmestad 2018; Marchenko et al. 2018; Andreassen et al. 2018). In the event of an abandonment of ship situation, requiring thousands of passengers to muster to either lifeboats or life rafts, the Polar Code states that resources, including the means to provide sustenance, shall be provided to support survival, whether on the water, ice or land, for the maximum expected time of rescue, defined to be at least five days (International Maritime Organization [IMO] 2017).

The provision of suitable and sufficient life-saving appliances (LSA) and arrangements on ships intended for polar voyages can be a demanding task for ship owners and operators (Solberg, Gudmestad, and Kvamme 2016; Solberg, Gudmestad, and Skjærseth 2017; Solberg and Gudmestad 2018), considering the total assembly of equipment that constitutes the entire emergency response system found on a ship. In the process of selecting LSA and arrangements, the enforcement of companies' safety philosophies and policies, established to comply with the Polar Code, could be challenged for both economic and practical reasons (Solberg, Gudmestad, and Skjærseth 2017). LSA and arrangements intended for polar water operations imply an additional budgetary cost (ibid.), compared to emergency equipment found on ships in tropical climates, due to the winterisation measures required in the design, preservation and packaging process. At the same time, in order to withstand the harsh polar environment, additional and winterised LSA and arrangements require space for storage and impose added weight on rescue craft. A reduction in the number of passengers could therefore emerge as a result of the additional equipment (Solberg, Gudmestad, and Kvamme 2016).

In the event of a survival situation, the provision of food and water is essential. However, humans can survive for weeks without food but only a matter of a few days without water (Piantadosi 2003), whether shipwrecked in the ice-infested and cold Arctic Ocean or stranded in the dry Sahara desert. The IMO guidelines applicable to LSA and arrangements (International Maritime Organization [IMO] 2019b) outline possible means of mitigating hazards, to comply with the Polar Code. They recommend food rations that provide a minimum of 5,000 kJ (1,195 kcal) per person per day and at least 2 litres of freshwater to be available per person per day for the maximum expected time of rescue (min. five days). The guidelines propose the use of desalting apparatus to provide the recommended amount of freshwater, and this could be a choice favoured by operators and ship owners equipping ships for voyages in the Arctic region.

The development and implementation of the above-mentioned guidelines on LSA and arrangements for polar waters (International Maritime Organization [IMO] 2019b) were driven by findings and experience from three survival exercises, performed in northern areas around Svalbard between 2016 and 2018 (Solberg, Gudmestad, and Kvamme 2016; Solberg, Gudmestad, and Skjærseth 2017; Solberg and Gudmestad 2018). These exercises led concerns being raised regarding the gaps explored between the expected performance requirements for SOLAS approved LSA and arrangements and the actual performance of related emergency equipment when tested in cold climate conditions (ibid.; Norwegian Maritime Authorities [NMA] 2019). The objectives for this experiment were, therefore, to verify the newly implemented guidelines and test the functionality of SOLAS approved desalting apparatus at low temperatures; to study the equipment's capacity to produce freshwater from seawater at various temperature readings; and to explore the salt rejection capacity at low temperature readings, by measuring salinity in the produced freshwater.

First, this paper presents the IMO regulatory framework applicable to ships operating in the Arctic region and regarding requirements for LSA and arrangements. Then, shipping in the Arctic region is discussed, considering environmental conditions, related hazards and mitigating winterisation measures associated with voyages in the harsh polar climate. The last part of the paper presents and examines the experiment of testing SOLAS approved desalting apparatus at low temperatures in a cold climate laboratory.

International maritime conventions and regulations applicable in the Arctic region

The International Convention for the Safety of Life at Sea (SOLAS) (International Maritime Organization [IMO] 2001) is reckoned to be the most important of all international treaties concerning the safety of merchant ships. The first version was adopted in 1914, in response to the Titanic disaster, later updated and amended on numerous occasions. The main objective of the SOLAS Convention is to specify minimum standards for the construction, equipment and operation of ships, compatible with their safety (International Maritime Organization [IMO] n.d.). The SOLAS Convention consists currently of 14 chapters, of which Chapter 3 (Life-Saving Appliances and Arrangements) and Chapter 14 (The Polar Code) are of interest in this paper.

Chapter 3 of the SOLAS Convention contains provisions for LSA and arrangements, including requirements for lifeboats, rescue boats and life jackets, according to the type of ship (International Maritime Organization [IMO] 2001). Chapter 3 makes further reference to *The International Life-Saving Appliance Code (LSA Code)*, providing specific technical requirements for LSA and arrangements (International Maritime Organization [IMO] 1998a). The performance requirements in the LSA Code can be supported by test or evaluation requirements as put forth in the *Revised recommendation on testing of life-saving appliances* (International Maritime Organization [IMO] 1998b), for defined survival equipment.

Chapter 14 of the SOLAS Convention (The Polar Code) (International Maritime Organization [IMO] 2017), amended in 2017, contains safety and environmental provisions for ships operating in defined geographical areas around the South and North Poles. The Polar Code's geographical area of application in the Arctic is shown in Figure 1 below.

The Polar Code states that ships' systems and equipment addressed in the regulation shall satisfy at least the same performance standards as those referred to in the SOLAS Convention (International Maritime Organization [IMO] 2017). The mandatory SOLAS Convention for merchant ships, therefore, constitutes a standardised minimum of expectations for the provision of safety measures for maritime design, equipment, systems and operations. Nevertheless, SOLAS approved LSA and arrangements, for use in emergency situations, can be found on ships in voyages all around the world, whether the

Figure 1. The maximum geographical extent of the Polar Code's area of application in the Arctic (International Maritime Organization [IMO] 2017).

climatic conditions are tropical or polar (Solberg and Gudmestad 2018). However, for the Polar Code and the utilisation of its function-based requirements, the main principle is based on the requirement to carry out an operational risk assessment of the ship and its equipment, in order to establish procedures or operational limitations, based on related risk factors in operating areas, such as ice conditions and temperature (International Maritime Organization [IMO] 2017, Ch. 1.5).

After the Polar Code came into effect, the *Guidance for navigation and communication equipment intended for use on ships operating in polar waters* was implemented (International Maritime Organization [IMO] 2019a), in addition to the aforementioned guidelines on LSA and arrangements for polar waters (International Maritime Organization [IMO] 2019b). Further, mandatory minimum requirements for the training and qualification of masters and deck officers on ships operating in polar waters were amended to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), applicable from 1 July 2018 (Norwegian Maritime Authorities [NMA] 2018).

The applicability of the Polar Code, with its goal to increase the safety of ship operations and to protect the vulnerable polar environment, is under discussion (Engtrø, Njå, and Gudmestad 2018; Engtrø, Gudmestad, and Njå 2020; Schopmans 2019); functional requirements vs performance requirements for LSA and arrangements, as well as the functionality of survival equipment and its capacity to perform adequately under cold climate conditions, are being questioned (Solberg, Gudmestad, and Kvamme 2016; Solberg, Gudmestad, and Skjærseth 2017; Solberg and Gudmestad 2018).

Shipping in the Arctic region – prevailing polar conditions and hazards

The Arctic region (Figure 2) extends to all the ice-covered Arctic Ocean and the surrounding land of Greenland and Spitsbergen and the northern parts of Alaska, Canada, Norway and Russia (Trantzas 2017). Climate conditions are characterised by long, cold winters and short, cool summers; the average winter temperatures range from −34°C to 0°C, and average summer temperatures range from −10°C to +10°C. The wind speeds over the Arctic Basin are between 4 and 6 m/s (7 and 12 knots) in all seasons. Stronger winds do occur in storms, often causing whiteout conditions (ibid.; Cohen et al. 2017). Rapidly developing low-pressure systems (polar lows) are common weather phenomena during winter seasons. Polar lows are characterised by sudden strong winds and low temperatures, heavy snow showers, thunder and lightning, choppy sea surfaces and increased wave heights; they can be hard to forecast and predict due to the nature of their development (International Standard [ISO] 2010; DNV GL 2015).

Some parts of the Arctic are covered by ice (sea ice and glacial ice) all year, and nearly all parts experience long periods with some form of surface ice (Trantzas 2017). However, the Arctic is not homogeneous with respect to prevailing environmental conditions. Considerable differences exist between not only seasons but also geographic locations. The

Figure 2. Map of the Arctic region (U.S. Department of State n.d.).

Beaufort and Chukchi Seas north of Alaska and Canada, for example, are covered with ice every year, whereas the south-western part of the Barents Sea off the coast of Norway is often said to be ice-free (DNV GL 2015).

Navigating in the Arctic region involves many challenges, due to the rapidly changing landscape of sea ice, draft restrictions in many areas, lack of hydrographic data and detailed surveys, less reliable navigation and satellite communication, and reduced visibility due to fog or darkness for long periods of the year (Hill, LaNore, and Véronneau 2015; Ghosh and Rubly 2015; DNV GL 2015). The presence of ice represents one of the greatest risks, with floating ice in many forms constituting an extremely hazardous condition if colliding with a ship in voyage, involving the risk of damage to hull and structure (Ghosh and Rubly 2015). Ice accretion caused by sub-zero temperatures and freezing of sea spray coming into contact with the ship's surfaces is the most hazardous form of icing and also the most common, and uncontrolled sea spray icing can represent a great risk regarding loss of ship stability, integrity and equipment failure (ibid.; International Standard [ISO] 2010).

Shipping across the northern polar region is increasing, connecting Asia and Europe by trans-Arctic routes along (Figure 3): the Northeast Passage (NEP) and the Northern Sea Route (NSR), encompassing the route along the Norwegian and Russian Arctic coasts; the North-West Passage (NWP), which follows Canada's northern coastline; and the

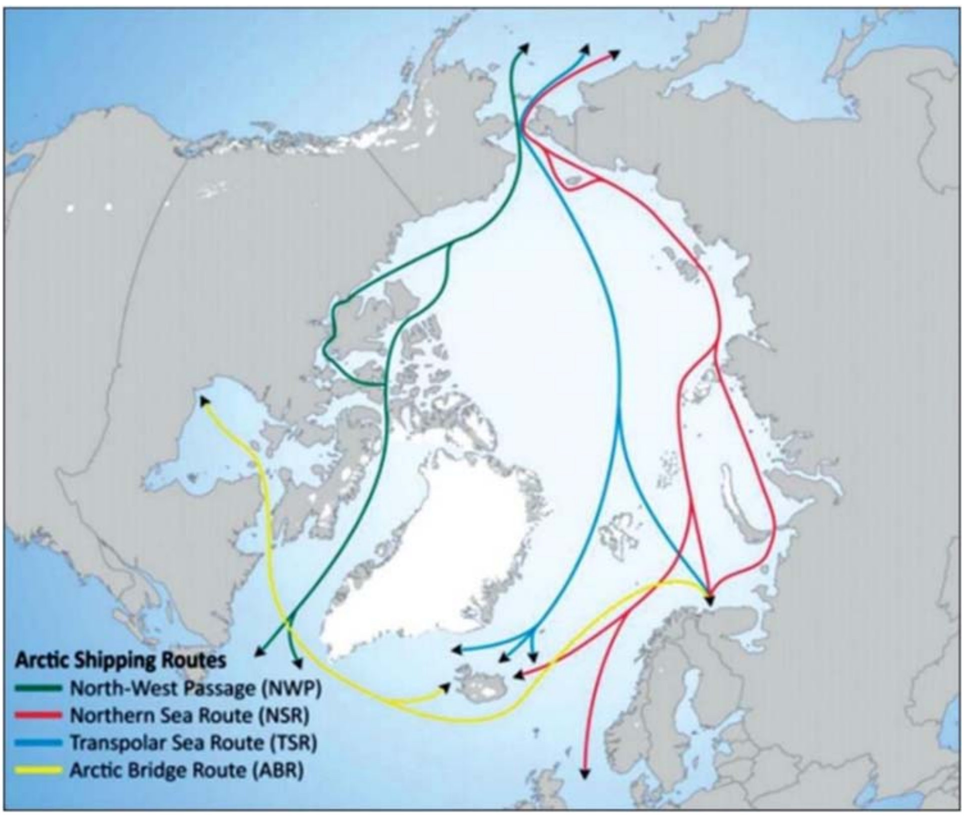


Figure 3. Shipping routes in the Arctic region (Humpert and Raspotnik 2012).

Transpolar Sea Route (TSR), which bisects the Arctic Ocean through the North Pole (Farré et al. 2014; Ghosh and Rubly 2015). In addition, the Arctic Bridge Route (ABR), a shipping route linking the Arctic seaports of Murmansk (Russia) and Churchill (Canada), could develop into a future trade route between Europe and Asia (Humpert and Raspotnik 2012).

Measurements of the volume of shipping within the Polar Code's geographical area of application in the Arctic, taken between 2013 and 2019, show a substantial increase in traffic, when counting both the number of individual ships (up 25 percent) and the total nautical distance sailed during the six-year period in the same area (up 75 percent) (Protection of the Arctic Marine Environment [PAME] 2020). The increase in ship traffic in recent years in the northern areas has been anticipated, especially due to the reduced sea ice enabling shipping in open waters between the Atlantic and the Pacific Oceans during short periods of the year (Grønnestad 2017). In 2016 and 2017, the passenger ship, Crystal Serenity, sailed through the North-West Passage (NWP) from Alaska to New York, with more than 1,000 passengers, on its first voyage (ibid.).

Search and Rescue (SAR) operations in the Arctic region can be extremely demanding, and considerable risks are presented should a ship suffer ice or heavy weather damage, grounding, or machinery failure, due to the extreme remoteness of the region and the limited readily deployable SAR facilities (Hill, LaNore, and Véronneau 2015). The potential for delays in emergency response and the lack of suitable emergency response equipment (Solberg, Gudmestad, and Kvamme 2016; Solberg, Gudmestad, and Skjærseth 2017; Solberg and Gudmestad 2018), in addition to the relatively low traffic density in the Arctic region, indicate that self-rescue is the core principle in the event of a maritime casualty and abandonment of ship (Larsen et al. 2016). An emergency situation involving thousands of passengers to be rescued from a cruise ship is deemed highly critical, as the size and the capacity of SAR services in the Arctic region are not prepared for such a scenario (Urke 2018).

Technical and operational winterisation measures capable of withstanding the harsh and prevailing climatic conditions in the Arctic region are therefore required on ships intended for polar water operations (DNV GL 2015). Winterisation measures are primarily targeted at limiting and controlling the adverse effects of freezing, icing, low temperatures and strong winds (wind chill). The main concerns are the protection of personnel and material properties (DNV GL 2015). Active winterisation measures are functional, addressing electrical or mechanical energy, e.g. heat-traced walkways and escape routes, heat-insulated piping (e.g. fire water lines), keeping circulation in lines to prevent liquid from being static (e.g. fire water mains and cooling water branch lines), or lowering the freezing point of fluids by adding chemicals (e.g. glycol). Passive winterisation measures are characterised as measures in which no energy is addressed, but the design, construction and packaging prevent the adverse effects of icing, freezing and wind chill, e.g. shielded walkways, escape routes and enclosed muster areas; the elimination of pockets, dead-ended pipes and legs in piping; extra insulation and packaging; and work clothing intended for low temperatures (DNV GL 2015; Ghosh and Rubly 2015; Engtrø and Gudmestad 2019).

Test of SOLAS approved desalting apparatus at low temperatures

Low temperatures can be critical for the composition of material used in emergency and survival equipment; steel and polymers become more brittle, and rubber sealing loses its flexible function and properties (DNV GL 2015). Reliance on LSA and arrangements being functional in an emergency situation is vital, and material weaknesses in survival equipment, not discovered until the accident is unfolding, can have fatal consequences. Previous studies performed on SOLAS approved LSA and arrangements, and their actual performance capacity under cold climate conditions, showed a discrepancy between expected and actual performance in the tested equipment (Solberg, Gudmestad, and Kvamme 2016; Solberg, Gudmestad, and Skjærseth 2017; Solberg and Gudmestad 2018).

The objectives of this experiment were therefore to verify the newly implemented guidelines on LSA and arrangements for polar waters (International Maritime Organization [IMO] 2019b) and test the functionality of SOLAS approved desalting apparatus, to study the equipment's capacity to produce freshwater from seawater within 60 min, at the following water temperature readings: +2°C, +4°C, +7°C, +10°C, +23°C. The desalting apparatus's salt rejection capacity was also explored by measuring salinity in the produced freshwater. The experiment was performed in a temperature controlled and enclosed environment, in the facilities at The Arctic University of Norway in Narvik.

General considerations, instrumentation and setup

The seawater for the experiments was sourced by boat in the Ofotfjord close to Narvik, a city in northern Norway. All required seawater was collected simultaneously, to provide the various tests with identical initial conditions with respect to water quality. To avoid a build-up of bacteria and algae, the seawater was collected in food-grade closed containers just in time to be acclimatised to the assigned test temperatures. The sealed containers also prevented evaporation and external contamination prior to the experiment.

The experiment was conducted in a temperature controlled and enclosed environment: an insulated room of about 40 m^2, cooled to the required test temperatures. The heating and cooling system is automatically regulated to sustain a given temperature. As the maximum temperature regulating capacity for the test facility is +10°C, the test performed at a room temperature of +23°C was conducted outside the insulated room, in a regulated indoor area – heating, ventilation, and air conditioning (HVAC), capable of maintaining a stable air temperature during the test, utilising the same measuring equipment used inside the insulated room.

In order to secure accurate temperature measurements, different sources of high-quality equipment were used: three sources of air temperature and two sources of water temperature. The log system was set to measure at one-minute intervals, providing 61 measurements for each test, with four variables: air temperature 1, air temperature 2, water temperature and relative humidity. In addition, measurements of water and air temperature were manually provided every five minutes with a Fluke instrument (Picture 7). The chosen sample interval provided an adequate set of information regarding the test environment and revealed, for example, variations caused by the periodic cooling system.

The instruments used during the experiment were a Hioki memory HiLogger LR8400-20 with two IEC code T – thermocouples and a Fluke 54 II B thermometer with 80PK-25 and 80PK-26 probes. During the tests, the instruments were situated close together to minimise the effect of varying temperatures within the test room. Measurements were also performed in close proximity to the test station, and care was taken to let the probes hang freely in the medium, not connecting to a surface (floor, wall, inside of the container, wires, etc.); see Picture 7. In addition, the relative humidity in the room was monitored by a Hioki Z2000 humidity sensor. A scale was used to control the amount of water, and the result was thereafter converted to litres by standard density values. A list of equipment, including range and error specifications, can be found in Table 1 below.

All equipment and infrastructure, except temperature sensitive equipment, was placed in the insulated room prior to the experiment, to acclimatise. Before being placed in the room, the containers with seawater were weighed and marked, to avoid disturbing the set temperature at the start of a test. While entering the room, care was taken to minimise the time the door was left open. Before starting a test, the temperature was verified to ensure that the room had stabilised after entry. Further considerations, preventative measures and challenges are described in Table 2 below.

After the five tests were completed, the salinity of the refrigerated samples was measured with a Hanna HI98192 USP compliant EC, TDS, NACL, resistivity temperature meter, with electrode HI763133. Between each sample, the probe was cleaned with distilled water.

Table 1. Equipment used in the experiment.

Equipment	Product specification	Comment
Salinity metre	Hanna HI98192 USP compliant EC, TDS, NACL, resistivity temperature metre, with electrode: HI763133	
Water sample container	VWR Borosilicate 3.3 500 ml 215–1594	Used for storing water samples
Volumetric glass	Schott Duran BlauBrand NS12/21 100 mL	Used for weighing liquid
Bucket 16 L	Product number Biltema: 86–2771	Used for wastewater
Bucket 40 L	Product number Biltema: 86–898	Used for wastewater
Mercury thermometer	Two glass mercury thermometers	
Fluke	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
Log system	Hioki memory HiLogger LR8400-20 no: 141208749. Temperature probes: T – thermocouple (IEC code). Hioki Z2000 humidity sensor no. 150430107.	IEC Tolerance Class EN 60584-2; JIS C 1602, class 1. Accuracy ± 0.5°C, range −40°C to +80°C
Cold room	PTG Kuldeteknisk AS	Range −30°C to +10°C
Water container 20 L	Transparent PEHD, approved for drinking water. Product number Biltema: 37–361	Used for transport and storing of seawater
Scale	August Sauter GmbH D-7470 Albstadt 1-Ebingen. Type AZ/N2E nr 0103016.	Range 2.5–120 kg. e =dd= 50g.
Desalting apparatus	Katadyn Survivor-35. Article No.: 8013433 standard.	Range water temperature +2°C to +45°C. Average salinity 35 ppt TDS.
Distilled water		Used to rinse the salinity probe

Table 2. Considerations, preventative measures and challenges identified for the experiment.

Concern	Preventive measure	Challenges during testing
Evaporation	The caps were left on until the containers were used.	
Spilt water	Care was taken to try to reduce spillage.	Some minor spillage occurred, approximating to less than 1 dl per test.
Leakages from the indicator on the desalinator	Prior to the experiment, time was spent becoming acquainted with the desalinator. During the tests, the pressure indicating rod was observed, in order to minimise leakages from the indicator.	
Rest water in containers	Care was taken to empty the containers properly.	The shape of the containers prevented the complete emptying of each container. Rest water, including water adhering to the inside of the container, approximated to less than 1 dl per container emptied.
Varying temperature as the containers were emptied	The container was changed before it was empty, and, if needed, the remaining water was added to the next container. This did not greatly influence the temperature, as the amount added was relatively small.	
Stop in pumping while changing water supply	The time lost while changing water supply was added to the end of the test, prolonging the test with x pumping motions.	
Reduced water intake as the container was emptied	To prevent the water supply to the pump being too small, a new container was provided prior to emptying the first.	
Manually operating the desalinator with a given frequency	A metronome was used throughout the experiment. The same person conducted all tests.	Adjustments to determine the appropriate metronome beat took place within the first minute.
Human error, manual logging	A checklist was used while logging manually observed data of weight and temperature.	
Inefficiency of the desalinator during start-up	To reduce the error in efficiency that would occur while filling the desalinator with seawater, two-three pumps were performed prior to starting each test. The processed clean water from this start-up was routed to the wastewater. The used water in this process was considered spilt water.	
Varying density with temperature	All containers were initially measured simultaneously at approximately +12°C.	Rest water and clean water were measured after each test with varying temperature. Three containers were measured at approximately +7°C.
Temperature variation	The containers were situated in the test temperature at least 12 h prior to the test, to secure a stable water temperature.	The air temperature varied as a result of repeated cooling in the test room.
Temperature spike because of entering	All equipment and infrastructure, except temperature sensitive equipment, was placed in the room prior to the experiment, to acclimatise. While entering the room, care was taken to minimise the time the door was left open. Prior to starting a test, the temperature was tested, to ensure that the room had stabilised after entering.	

(*Continued*)

Table 2. Continued.

Concern	Preventive measure	Challenges during testing
Accuracy of weight measurements	Available measuring instrument for the weight was used. Between measurements, the scale was reset.	The scale rounds to the closest 0.5 kg.
Accuracy of salinity measurements	To ensure a similar salinity level in all tests, all seawater was sourced simultaneously. In addition, the water was sourced far from the shore, where salinity levels are lower, due to outflow of freshwater. Samples were secured in clean glass containers and kept refrigerated until testing. Prior to each salinity test, the probe was rinsed with distilled water.	
Accuracy of temperature measurements	Different sources of high-quality equipment were used. Prior to the experiment, a test was performed with four instruments for measuring water temperature. During the tests, the instruments were situated close together, to minimise the effect of varying temperatures within the test room. Measurements were also performed in close proximity to the test station. Further, care was taken to let the probes hang freely in the medium, not connected to a surface (floor, wall, inside of container, wires, etc.).	
Desalinator functionality	Instructions were followed.	
Storing of the desalinator between tests	To prevent the storage of the desalinator to influence the result, 4 out of 5 tests were performed within the time span of 5 h.	One test, at +2°C, was performed the following day, and some discrepancy could occur as a result of overnight storage of the desalinator.

Katadyn Survivor-35 desalinator

The Katadyn Survivor-35 desalinator (Picture 8), tested in the experiment, is specified by the vendor as an approved desalting apparatus, as defined in the 1983 conditions of the SOLAS Convention.

The desalinator is a hand-operated pump – intended for emergency situations, for the provision of freshwater from seawater – whose materials consist of stainless steel and plastics. The equipment utilises reverse osmosis and high pressure to remove dissolved salts from seawater, which is filtered through a semipermeable membrane (Figure 4). The semipermeable membrane acts as a molecular filter, and when the pump pressurises seawater to 55 bar and forces it against the membrane, only the water molecules can pass through; salt molecules are unable to pass and flow out of the system.

The desalting apparatus tested in the experiment was provided by a recognised Norwegian shipbuilding company which designs and builds standardised – as well as highly specialised – Polar Code-certified ships. The Katadyn Survivor-35 desalinator is part of the survival equipment, making up the total assembly of LSA and arrangements, delivered by the shipbuilding company to ships intended for polar water operations.

Operating instructions for the Katadyn Survivor-35 desalinator

The Katadyn Survivor-35 is designed to operate during conditions with seawater temperature specifications ranging from +2°C to +45°C and average salinity levels of 35 parts per thousand (ppt) Total Dissolved Solids (TDS). The desalinator is specified to provide 4.5 litres of freshwater per hour (+/- 15%), with an average salt rejection capacity of 98.4% and a minimum of 96.8%. The manual specification states that degree of desalination depends on factors such as water temperature and salinity.

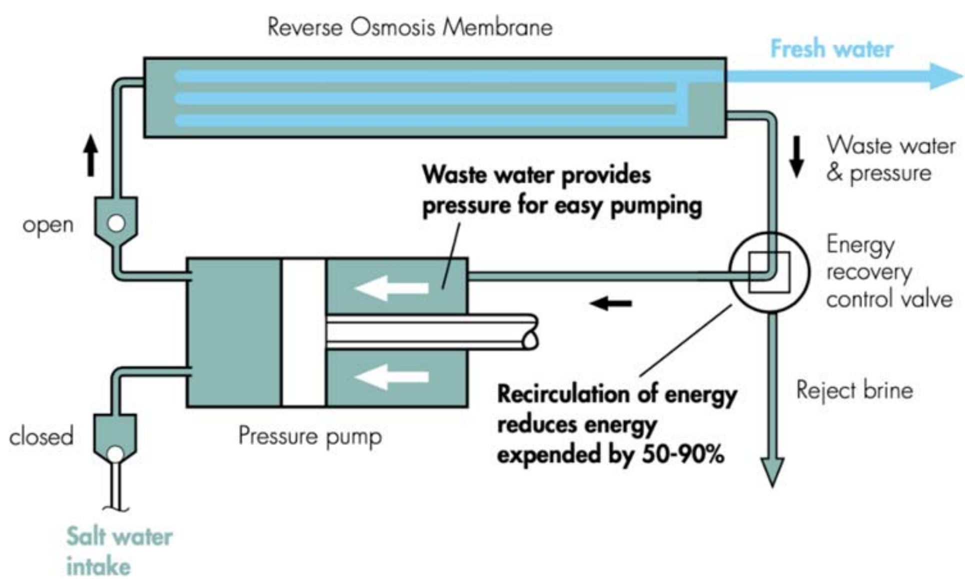


Figure 4. Reverse osmosis technology (Katadyn Fact Sheet n.d.).

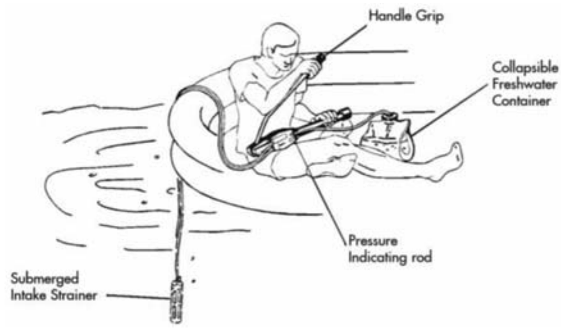


Figure 5. Illustration of a person using the Katadyn-35 desalinator, sitting in a life raft (Katadyn Manual n.d.).

The hand-operated desalinator is to be placed on the lap, with one hand on the handle grip and the other on the membrane housing, as shown in Figure 5. The intake and discharge hoses, attached in a strainer, shall be fully submerged into the seawater, and the freshwater hose is to be placed into a storage container (or directly into the mouth). Optimum pump frequency is set to be 30 strokes (up and down) per minute. If the pump frequency is too fast, a pressure indicating rod extends itself and, finally, water sprays from the indicator.[1]

Operating criteria for the desalinator

Operating criteria established in the experiment for the desalinator directed the pumping frequency and were monitored by observing the pressure indicating rod; it determined that pumping should be as fast as possible but without water spraying out from the indicator (Picture 9). If water sprayed out, the pump frequency was lowered. As soon as an optimum pump frequency was established, a metronome was used to ensure that a steady pump frequency was maintained during the 60-minute test. The same person operated the desalinator in all the tests performed.

Discussion concerning measuring accuracy and deviations

Salinity

Ocean salinity is generally defined as the salt concentration (e.g. sodium and chloride) in seawater and often described in units of ppt. Salinity can also be expressed in Practical Salinity Units (PSU): a measure of the water conductivity at a constant pressure and temperature that is about equivalent to ppt (CATDS – Ocean Salinity Expert Center n.d.).

The seawater samples from the Ofotfjord were measured to a salinity of 26.8 ppt, whereas the average salinity of seawater is 35 ppt (International Standard [ISO] 2019). The seawater samples were gathered less than 0.5 m below the surface. Collecting water from the upper sea layer combined with the fjord location is assumed to give the resulting deviation from average seawater salinity.

Presumably, lower salinity levels in the seawater could result in better test results for the desalinator's capacity to produce freshwater and reject salt molecules. Therefore,

Table 3. Test results with lower salinity levels.

Seawater temperature [°C]	21.3	23.1
Seawater salinity [ppt]	5.0	26.8
Cleaned water salinity [ppt]	0.06	0.12
Cleaned water [kg]	6.8	5.3

an additional test was performed with seawater gathered from Ornesvika, with a salinity measured at 5.0 ppt. Compared with the test results from seawater with a salinity of 26.8 ppt, with otherwise comparable conditions, the processed water with initial lower salinity levels also contained less salt; see Table 3. The low salinity test also yielded a higher amount of cleaned water. However, the discrepancy in the amount could be due to a watch being used to sustain the manual pumping rhythm in the low salinity test: a method found to be somewhat inaccurate. The results are inconclusive, and a test of the desalinator's efficiency at different salinity levels could be explored. Nevertheless, the results are within the prescribed margins of the desalinator.

The desalinator used in the experiment is designed to operate with an average seawater salinity of 35 ppt, expressed in TDS, and measurements of both salinity PSU and TDS were performed. The concepts of salinity PSU and TDS are very similar, with TDS being a measure of the total ionic concentration of dissolved minerals in water. Since most dissolved solids in seawater typically consist of inorganic ions, which are the components of salts, the concepts are sometimes considered to be synonymous (Fondriest n.d.).

Temperature measurements

During the tests, different measuring instruments were used: three measures for air temperature, and two temperatures for the liquid entering the desalting apparatus. Consequently, some discrepancy between the measurements occurred.

Prior to the experiment, a point sample with two additional instruments was performed for the crucial water temperature, as shown in Table 4 below. The Fluke 54 II B thermometer with the appropriate water temperature probe, the Hioki HiLogger LR8400-20 with T-thermocouple and two submergible mercury thermometers were tested simultaneously.

The initial investigation with one sample is far from an adequate calibration of the temperature instruments. However, it confirmed that differences in temperature would occur as a result of using different measuring instruments. Moreover, the discrepancy in the result was not alarming and did not discourage further use of the tools.

After the experiment, the results from all measurements were averaged to investigate the difference between the individual instruments, as shown in Table 5 below.

The difference in air temperature averaged from all measurements included in the experiment shows a difference of approximately 0.6°C higher temperature from the

Table 4. Test of measured seawater temperature one-point sample [°C].

Hioki memory HiLogger LR8400-20 with T – thermocouple	8.8
Mercury thermometer 1	9.5
Mercury thermometer 2	11
Fluke 54 II B thermometer with 80PK-25 probe	10

Table 5. Difference between the individual measuring instruments.

	Hioki T-thermocouple 1, air	Hioki T-thermocouple 2, air	Fluke B54, 80PK-26 air	Hioki T-thermocouple 3, water	Fluke B54, 80PK-25 water
Average of all measurements [°C]	7.1	7.1	7.7	8.8	9.2
Difference from Fluke [°C]	−0.6	−0.6		−0.4	

Fluke instrument than the thermocouples connected to the Hioki system. Similarly, the difference in water temperature was averaged to about 0.4°C higher with the Fluke equipment.

The instruments were placed in close proximity to each other to avoid the effect of location-dependent temperature variations. Some difference in temperature could be explained, as the devices utilise different types of thermocouples. Types K (Fluke) and T (Hioki) contain distinctive alloys as electrical conductors, respectively chromel vs alumel and copper vs constantan. The standardised accuracy of the thermocouples is given in Table 2. The difference in temperature is within the margin of required accuracy.

Standard deviations in the dataset from mean values give a sense of the data spread. The largest standard deviation for water temperature, 0.29°C, occurred at room temperature with the Fluke instrument. The largest standard deviation for air temperature, 0.79°C, was measured with the t-thermocouple when the cooling system was set to one degree Celsius. As shown by the two green lines in Figure 6, almost indistinguishable from each other, the air temperature varied in cycles. Additionally, Figure 6 shows the disturbance in temperature caused by entering and exiting the test facility. The thermal capacity of water is evident from the stable temperature illustrated by the lilac graph throughout the

Figure 6. Hioki logger plot output showing the disturbance in temperature caused by cooling cycles and entering and exiting the test facility.

repeated cooling cycles and opening the door. The red graph indicates the measurements of relative humidity. The relatively larger standard deviation for air temperature can, therefore, be explained by the continued cooling cycle in the test facility.

When comparing measurements performed with Hioki vs Fluke, the temperature variations followed a similar pattern or trend.

There is a correspondence between the different temperature measurements, and the greater standard deviation in air temperature is mainly due to the heating/cooling cycles of the environment. In the following chapter, the average results from the Fluke instrument are chosen to represent the values for air and water temperature.

Results and discussion

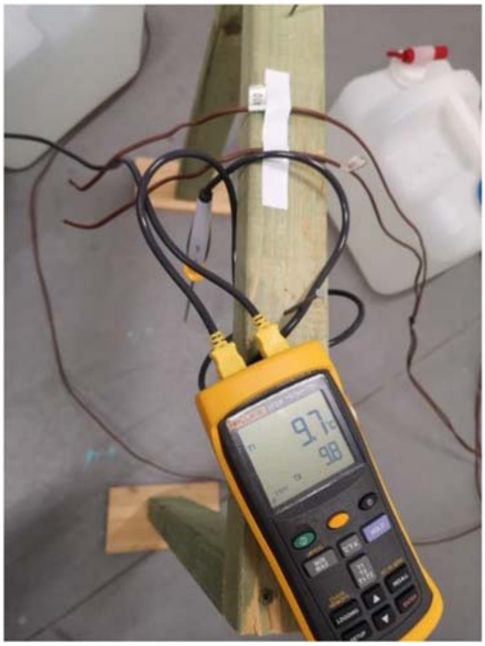
The desalinator`s capacity to produce freshwater was significantly reduced at lower temperatures, but minor variations in the salinity levels were observed at the same temperature readings; see Table 6 below.

In the test performed at +23°C, the desalinator produced 5.4 litres of freshwater within 60 min, which is above the maximum specification. At +10°C, the desalinator produced 4.5 litres of freshwater, which is the average specification. In the remaining tests performed at +7°C, +4°C and +2°C, the desalinator produced less freshwater than the minimum specification for the equipment. The pump frequency during the test at +2°C was the same (17.5 bpm (bpm)) as in the test performed at +4°C; however, the frequency could have been reduced to 15 bpm in the test at +2°C, as the indicator occasionally sprayed out some water during this test, which did not occur at +4°C. Dividing the amount of freshwater produced by the total number of pumps performed during a 60-minute test gives an approximate 0.003 litres freshwater produced per pump. Reducing the pump frequency to 15 bpm in the test performed at +2°C would have resulted in 2.7 litres of freshwater (15 bpm×60×0.003 litres), instead of the 3.2 litres produced in the tests performed at +4°C and +2°C. The test performed at +2°C was conducted the day after the other tests; during this period the desalinator was stored at room temperature. This pause could potentially have had an effect on the desalinator's capacity to reject salt molecules; the salinity level measured in the test performed at +2°C (0.36 ppt) was higher than in the other test results but still well within the specification for the desalinator; average salt rejection capacity is set to a salinity level of 0.43 ppt and a minimum of 0.86 ppt. The low salinity levels measured in the produced freshwater could be associated with an initial lower salinity level in the collected seawater (26.8 ppt) than the average salinity specification of the desalinator (35 ppt).

Reliable data on the possible health effects associated with the ingestion of TDS in drinking water are not available (World Health Organization [WHO] 1996). Nevertheless, the presence of dissolved solids in water may affect its taste (Bruvold and Ongerth

Table 6. Test results of processed seawater at the various temperatures; initial salinity level PSU 26.8.

Mean seawater temperature [°C]	2.2	3.7	6.9	9.9	23.1
Mean air temperature [°C]	0.3	2.3	6.9	9.4	19.8
Desalted water obtained over 60 min [litres]	3.2	3.2	3.6	4.5	5.4
Pump frequency [bpm]	17.5	17.5	20	25	30
Salinity PSU for processed water [ppt]	0.36	0.19	0.15	0.11	0.12



Picture 7. The Fluke 54 II B thermometer and probes measuring air temperature, taped to a wooden rail. The photo was taken during the test performed at +10°C.

1969), defined by water's organoleptic properties, evaluated by objectionable smell and tastes, odours, colours and turbidity. The palatability of drinking water, rated in relation to its TDS levels, is categorised as: excellent, less than 0.3 ppt; good, between 0.3 and 0.6 ppt; fair, between 0.6 and 0.9 ppt; poor, between 0.9 and 1.2 ppt; and unacceptable, greater than 1.2 ppt (World Health Organization [WHO] 1996). The quality of the produced freshwater in the experiment can therefore be categorised as excellent in four of the tests and good in the test performed at +2C°, considering the evaluation of taste, sight and smell.

Previous studies exploring the expected performance criteria for survival equipment in cold climate conditions show a significant reduction in the tested equipment`s functionality (Solberg, Gudmestad, and Kvamme 2016; Solberg, Gudmestad, and Skjærseth 2017; Solberg and Gudmestad 2018). The maximum expected time of rescue is defined in the Polar Code as the time adopted for the design of equipment and systems that provide survival support and shall never be less than five days (International Maritime Organization [IMO] 2017, Ch. 1.2.7). In this experiment, the desalinator was only exposed to low temperatures during each test and for a total of five hours. The use and storage of the desalinator over a five-day period in cold climate conditions could potentially affect the equipment in a way which was not explored in this experiment, due to set time limitations for the entire project.

Conclusions and recommendations

The test of the desalinator revealed that low seawater temperatures had a negative effect on the desalting apparatus`s capacity to produce freshwater, showing the importance of testing

Picture 8. Katadyn Survivor-35 desalinator (Katadyn Fact Sheet n.d.).

Picture 9. The (white) pressure indicating rod, extending from the (black) indicator housing while pumping. The freshwater outlet hose is seen above. The photo was taken during one of the tests.

essential survival equipment in cold climate conditions, to reveal weaknesses and challenges not experienced in a tropical climate. This experiment provided a controlled and monitored environment that could be difficult to achieve in the field. A similar experiment could be conducted in outdoor areas, to explore added stress elements and on-site challenges which might appear; e.g. operating the desalinator from a lifeboat vs a life raft would increase the distance to sea surface, considering the limited length of the desalinator`s seawater inlet hose (see Picture 8), which hypothetically could introduce a practical challenge.

A standardised test for desalting apparatus should be developed, similar to the temperature cycling tests described in the *Revised recommendation on testing of life-saving appliances* (International Maritime Organization [IMO] 1998b). In addition, if this type of survival equipment is planned for in the provision of freshwater, the ship's operational risk assessment should reflect the desalting apparatus`s reduced capacity to produce freshwater at low seawater temperatures, which could be compensated for by carrying additional desalting apparatus.

Note

1. In the manual specifications for the Katadyn-35 desalinator (Katadyn Manual n.d.), an orange band on the pressure indicating rod is described, revealing itself when pumping the handle. The purpose of the orange band is to determine pump frequency; pump frequency should be maintained as long as the orange band remains visible. If water sprays from the indicator, pump more slowly. If the orange band is not visible, pump faster. However, there was no orange band on the desalinator tested in the experiment.

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No potential conflict of interest was reported by the author(s).

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