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Study on a Marine Desalinator Fitted Onboard a Ship

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Abstract. In accordance with WHO (World Health Organization) requirements, the water to be used as drinking water on board ships must be supplied in good sanitary condition, from a shore source, through the distribution system at the shore facilities, through the connections of the distribution system between the shore facility and the ship, through the drinking water distribution system on board, at the end of which are included all the taps on board. At the same time, seawater desalination and purification systems are accepted as sources of drinking water on board ships as long as all measures are taken to prevent contamination or pollution of the water during transport or operation of the ship. The legislation to be complied with by each ship operator who is required to provide assistance to the vessels he manages in the field of drinking water supply, storage and distribution and use, must take into account the relevant legislation applicable in this field. It includes the following regulations and sets of rules: *International Health Regulations* (IHR) developed by WHO, *European Union Directive on Drinking Water on Board* (DWD) 98/83/EC, MLC Code 2006 (Standard A.32 - Food and Catering) and WHO - *Guide to Sanitary Services on Board Ships*, Third Edition of 2011 and *Drinking Water Quality Regulation* on Board Ships of 2008.

1. Introduction

In accordance with the provisions set out in the 2006 MLC Code, section "Frequent inspections of drinking water", on-board drinking water installations must be carried out frequently. This allows ship operators to ensure that they take all necessary measures to ensure the purity of drinking water on board. In order to ensure a certain consistency in the quality of drinking water on board the ship, it is recommended that it be checked at least twice a year. The frequency of on-board water quality checks will be determined, by the following basic criteria which an operator should essentially summarize:

- Frequency of supply of drinking water to the ship;
- Refreshing the water supply using on-board desalination plants;
- Visual analysis;
- Monitoring of desalination and water treatment procedures (checking and optimizing the treatment system in accordance with the desalination plant manufacturer's instructions, operating instructions, ultraviolet sterilization system, plant cleaning, etc.)

Vessels with living quarters (including most seagoing vessels) must be provided with a mandatory drinking water system. Drinking water filling holes and drinking water hoses must be marked as intended exclusively for the circulation of drinking water. Drinking water supply necks must be located above the deck. Drinking water installations on board ships must meet at least the three basic conditions:

- be made on the inner surface of a material which is resistant to corrosion and does not present any physiological danger;
- not to have pipe sections in which a continuous flow of water is not guaranteed;
- be protected against excessive heating.

In addition to the above provisions, drinking water tanks must meet a minimum of conditions, as follows:

- have a capacity of at least 150 l per person normally living on board and at least per member of the minimum crew;

- have an adequate opening, which can be locked and which allows the interior to be cleaned;
- have a water level indicator;
- have ventilation ducts leading to the open air, fitted with appropriate filters.

Drinking water tanks (tanks) must not have common walls with other tanks, especially fuel or oil tanks. Drinking water pipes must not pass through tanks containing other liquids. Connections between the drinking water supply system and other pipes are not permitted. Pipes through which other liquids or gases are transported must not pass through drinking water tanks.

Drinking water hydrophores should only operate with uncontaminated compressed air. If compressed air is obtained by means of compressors, suitable air filters and oil separators must be installed just in front of the hydrophore, unless water and air are separated by a membrane.

2. Main Technical Means of Water Desalination

While some see it as a "panacea" for the global water crisis, environmentalists blame the desalination process for destroying marine ecosystems. Studies show that only three percent of the planet's water is safe to drink and, after all, Thus, while an American consumes an average of 600 liters of water a day, an African consumes only 10 liters. Dozens of African countries face an acute shortage of drinking water on a daily basis, while some people in Europe and America are just turning on the tap so that the water flows in abundance.

Specialists say that a population that benefits from drinking water sources below the value of 1,700 m^3/year/inhabitant is under water stress. In this situation is a large part of the world's population. In some countries, the water shortage crisis is already catastrophic. For example, in Kuwait, a inhabitant consumes only 10 m^3 of water per year, and in the United Arab Emirates, only 58 m^3/year. That is why these two states have invested in desalination and occupy the first places in the world in this respect. At the same time, the Algerian authorities had to look for other sources to guarantee the country's supply of drinking water. The most suitable solution, which does not depend on the vagaries of the weather, is the desalination of sea water.

Desalination of seawater allows supplementing the available drinking water resources, providing a solution in case of drought and solving situations of scarcity and crisis. Therefore, desalination is a viable solution, able to remove the vagaries of the climate. However, in the opinion of some specialists, this technology does not only have advantages. First of all, it is very expensive. Desalination of ocean water requires a huge consumption of energy and is therefore a major producer of greenhouse gases.

Desalination plants endanger marine ecosystems. In a report on ocean water desalination plants, representatives of the environmental organization WWF (World Wild Fund) did not hide their concern about this issue: *"Desalination of seawater is far from the ideal solution. This technology poses a potential threat to the environment and will only exacerbate climate change. The use of these new technologies, which are becoming more and more accessible, will not be without consequences for the environment"*, warned the WWF representatives in their report. In addition, the members of the organization estimate that the internal desalination activities can lead to the destruction Coastal waters, wetlands, groundwater and, in general, ecosystems that provide water purification and protection against disasters are thus endangered, and specialists in marine pollution and ecotoxicology have also sounded the alarm about the consequences. adverse events that could occur after the commissioning of the El Hamma seawater desalination plant.

On the other hand, some experts believe that this technology will not be cost-effective until nuclear power is widely used to provide the kilowatts needed for both electricity generation and drinking water. Such an alliance has already taken place in Aktau, Kazakhstan, which has been in operation since 1973.

Another positive example in this regard is the Chinese model that aims to connect the Tianjian desalination plant to an atomic reactor. The factory will produce by distillation with heat supplied by the reactor, high quality water. China National Offshore Oil Company (CNOOC) plans to build in the

Caofeidian industrial region, the largest seawater desalination plant that will process 1.4 million tons of seawater daily, a quantity that will meet the water needs of the industrial area. and will also serve the capital Beijing.

But the best example of the economic profitability of water desalination is provided by the state of Israel, a true pioneer in the field of desalination. Ashkelon is home to one of the largest desalination centers in the world that uses reverse osmosis. The cost of desalination of one cubic meter of water for the state of Israel varies between 2.5 - 3.1 shekels, while the damage caused by drought if the land is not irrigated, reaches 8 shekels. Thus, desalination of water proves to be a cost-effective method for the state of Israel.

The race to build seawater desalination plants began in 1975 when there were already around 1036 such plants worldwide, with a production of 2.1 million m^3/day. In 1991, their number reached 2,154 units, with a daily capacity of 6.8 million m^3.

Today, the Gulf countries have the largest number of treatment plants. For example, in Saudi Arabia there are capacities of about 3 million m^3/day, in the United Arab Emirates 800,000 m^3/day, Kuwait 600,000 m^3/day, and in Iran 100,000 m^3/day.

On the European continent, desalination technology is already in operation in several countries, such as Italy, Greece, Belgium and the Netherlands. For example: in Spain, the first units were installed in the Canary Islands in 1980s. Moreover, Spain ranks fifth in the world in terms of obtaining drinking water by desalination, with the 900 units it has. On the Spanish coast, Carboneras is home to the largest seawater desalination plant in Europe. It has a capacity of 120,000 m^3/day and supplies fresh water to both the agricultural sector and tourism.

Figure 1: Nuclear seawater desalination plant in Aktau, Kazakhstan [2]

The other process, reverse osmosis, requires the pre-treatment of seawater to get rid of the suspended elements and the microorganisms it contains. The process then consists in applying this salt water to a pressure sufficient to cause it to pass through a semi-permeable, very dense membrane. In this way, only the water molecules cross the membrane, thus providing drinking water. The major drawback of these systems is the very high price of the installation.

The amount of energy required to heat or compress the water is very large and the volume of water obtained is very small. Therefore, the use of seawater desalination remains a marginal technique. But these techniques are the subject of countless research just to make them more cost-effective.

For desalination, the method based on freezing salt water can also be used: after freezing, the ice crystals are separated, cleaned and melted, resulting in pure water.

In the context of the current economic development and the higher and higher targets that the economic agents set every year, it is estimated that the (fresh) water demand will be higher and the reserves lower. This has been and will continue to be a source of conflict of a greater or lesser potential. In the context of land degradation, the magnitude of the desertification phenomenon and population growth correlated with the increased need for food globally, water will be one of the most important sources of conflict. If the 20th century was dominated by wars aimed at controlling energy sources (oil, gas), in the 21st century, water will generate the premises for future armed conflicts.

The gap between the price of desalinated water and the price of treated water today is an important reason why investment in this area has not grown. But in the future, due to technological progress and the improvement of technologies, it is possible that desalinated water will become as accessible as treated fresh water.

Under current conditions, which require 2,000 to 4,000 liters of water to produce a single kilogram of rice, Asia's staple food, Stockholm experts have agreed on the need for international law to regulate equal opportunities in this area. and reduce the danger of conflict. Along with oil, water will play a key role in policy decision with regional and global economic effects, reorienting expertise, people and important financial resources.

Desalination of water is, in fact, a decrease in the concentration of salts dissolved in it. The procedure can be total in nature, when the liquid is free of any salt content or partial, when the prescribed amount of salt will remain in the water content.

Complete desalination methods are performed in the following technologies and processes:

- Distillation, thermal method;
- Ion exchange method;
- Electrodialysis method;
- Reverse osmosis membrane.

Partial salt removal is performed when the following processes are applied:

- Liming;
- Soaking bars;
- Cation exchange;
- Freezing.

Water desalination methods require both financial and energy costs. The choice of treatment method depends on the degree of salt content in the original liquid, the capacity of the installation, the costs of process components (heat, electricity, reagents). Each of the methods has its own advantages, disadvantages and takes place with the help of technical means. Each of the water desalination methods has both positive and negative characteristics, some of which would be:

- Ion exchange - helps to obtain the purest water, the system is reliable and does not respond to the initial degree of mineralization liquid, low equipment costs are needed. The desalination process takes place at minimal flow losses. Disadvantages of the method include rapid contamination of the environment with harmful chemicals, high cost of the reactants themselves, the system quickly becomes dirty and requires frequent filter replacement. Disposal and filter can be difficult.

- Distillation - installations for the production of water by desalination based on the thermal method used without the use of chemicals have a good quality of the resulting liquid while the heat generated in this process can be used for other purposes. The distinctive feature of this method is the possibility to eliminate dissolved gases. The disadvantages of the method are: high energy costs, the need for water treatment, installation maintenance costs (cleaning of all parts), high cost of equipment;

- Membrane systems are different, being characterized by the initial robustness needed to generate water, but also by the fact that the process does not need chemicals, being very easy to maintain. The negative aspects of this type of operation would be: the preparation of a water treatment process, a large amount of water for the operation of the devices, high energy consumption, which affects the cost of the final product.

On board the ships the most used technologies used to obtain fresh water from sea water are desalination by distillation and osmosis.

3. Study of a Desalinating System Fitted Oboard a Commercial LNG Tanker

For this study as the reference ship the PCG "ARATOS" Liquefied Natural Gas Carrier (LNG Tank) has been chosen. The ship can also transport ethylene, VCM, Ammonia and Propane, also being considered a chemical tanker.

Figure 2: The PCG *"Aratos"* LNG carrier ship chosen as the reference ship for this study [2]

The flow capacity for the fresh water pumps, domestic water pumps or sea water pumps is:

$$Q_p = \sum_i (n_i \alpha_i q_i)$$

The parameters in the above formula are:

- n – the numbers of fresh water or sea water consumers onboard;
- α – the simultaneity coefficient for consumers that have the same operating parameters;
- q – the consume standard, measured in [l/s], which has a typical value for each consumer.

The values for the simultaneity coefficient and for the consume standard depending on the type of consumers are:

- For washbasins: α = 0,3 and q = 0,07 l/s;
- For showers: α = 0,2 and = 0,2 l/s;
- For simple washers: α = 0,4 and q = 0,15 l/s;
- For double washers: α = 0,5 and q = 0,3 l/s;
- For bathtubs: α = 0,25 and q = 0,2 l/s.

Thus according the above values the following values are to be used in the following calculus procedures:

- $\alpha_1 = 0{,}3$; $q_1 = 0{,}07$;
- $\alpha_2 = 0{,}2$; $q_2 = 0{,}2$;
- $\alpha_3 = 0{,}4$; $q_3 = 0{,}15$;
- $\alpha_4 = 0{,}5$; $q_4 = 0{,}3$;
- $\alpha_5 = 0{,}25$; $q_5 = 0{,}2$.

Onboard the PCG "Arators" the following fresh water consumers can be found:

- washbasins - $n_1 = 55$;
- showers - $n_2 = 48$;
- simple washers - $n_3 = 5$;
- double washers - $n_4 = 4$;
- washtubs - $n_5 = 4$;

Thus the total water flow needed for the fresh water system will be calculated using the following formula:

$$Q_p = n_1\alpha_1 q_1 + n_2\alpha_2 q_2 + n_3\alpha_3 q_3 + n_4\alpha_4 q_4 + n_5\alpha_5 q_5$$

After the values for the above parameters have been replaced the following values are obtained:

$$Q_p = 4{,}175\ \frac{l}{s}$$

Thus, the total water flow needed for the installations are, after the transformations are don:

$$Q'_p = Q_p 3{,}6$$

$$Q'_p = 15{,}03\ \frac{m^3}{h}$$

The hourly numbers in which the pump starts is i = 7 – 9, thus this number is equal to 8, and this value will be used for the calculus of the fresh water generator as it follows. Its volume will be:

$$V = \frac{Q'_p}{i}$$

$$V = 1{,}879\ m^3$$

The hydraulic losses calculus is:

$$h = \lambda\ \frac{l_c}{d}\rho\frac{v^2}{2}$$

Where the recommended values for the speed of the water flowing through the pipes v_{rec} is:

$$v_{rec} = 1 \ldots 1{,}2\ \frac{m}{s}$$

Knowing that $v = v_{rec}$ than the following value is being chosen:

$$v = 1\ \frac{m}{s}$$

The pipework diameter is calculated using:

$$d' = \sqrt{\frac{4Q_p}{\pi v_{rec}}}\ m$$

$$d' = 0{,}0729\ m$$

$$d_{mm} = 72{,}909\ mm$$

Using the values specified in naval engineering for freshwater systems pipework the diameter will become:

$$d_m = 0{,}076\ m$$

The kinematic viscosity will be calculated as it follows:

$$\nu = 1{,}287 \cdot 10^{-6}\ \frac{m^3}{s}$$

The kinematic viscosity will be calculated at a environmental temperature equal with to 12 ^{0}C. Thus the Reynolds number will be:

$$R_e = \frac{v d_m}{\nu} = 5{,}921 \cdot 10^4$$

For the steel welded pipes, which are new and galvanized, the asperity height is being considered:

$$K = 0{,}1 \ldots 0{,}2\ mm$$

Thus:

$$\varepsilon = \frac{K}{d_{mm}} = 2{,}057 \cdot 10^{-3}$$

Applying the Altsul criteria the Reynolds numbers will be calculated as:

$$R_{e1} = \frac{10}{\varepsilon} = 4{,}861 \cdot 10^3$$

$$R_{e2} = \frac{500}{\varepsilon} = 2{,}43 \cdot 10^5$$

The basic condition for this type of water system is $R_{e1} < R_e < R_{e2}$ which is obviously being fulfilled then the pipework is a semi roughed surface, hydraulic speaking and the hydrodynamic friction coefficient will be calculated:

$$\lambda = 0{,}11(\varepsilon + \frac{68}{R_e})^{0{,}25} = 0{,}026$$

Afterwards, the calculus length l_c and the equivalent length l_e can be easily done. According with the technical features of the LNG carrier, for the calculated pipework previously calculated the following equivalent lengths will be taken into account:

- $l_v = 25$ – for the needle valve;
- $l_c = 5{,}2$ – for a bent in the pipework layout;
- $l_t = 5{,}2$ – for a T type junction on the pipework layout;
- $l_{ct} = 14$ – for the sea water strainer;
- $l_{CT} = 0{,}55$ – for a fully opened water valve.

Thus the equivalent lent shall be:

$$l'_e = 2l_v + 7l_c + 2l_t + 1l_{ct} + 5l_{CT} = 113{,}55\, m$$

The value of length taken into consideration for the precision of the calculus will be, depending on the total length of the ship:

$$l_c = (10 + 2 + 1 + 0{,}7) \cdot 12 = 164{,}4\, m$$

The pump load generated by the local losses is:

$$h = \left(\lambda \frac{l_c}{d_m} + \lambda \frac{l'_e}{d_m}\right) \rho \frac{v^2}{2} = 4{,}774 \cdot 10^4\, Pa$$

The total pump load resulted having in mind the hydraulic losses on the fresh water system, as well as the losses for the discharge height are:

$$H_i = \rho g z + h = 1000 \cdot 9{,}81 \cdot 16{,}4 + 4{,}774 \cdot 10^4 = 2{,}086 \cdot 10^5$$

The minimum pressure in the fresh water generator shall be:

$$p_1 = H_{fwg} = 2{,}086 \cdot 10^5$$

The maximum pressure in the fresh water generator is:

$$p_2 = \alpha p_1 = 1{,}6 \cdot 2{,}086 \cdot 10^5 = 3{,}755 \cdot 10^5$$

Were $\alpha = 1{,}5\ldots2$ is a coefficient depending on the pressure difference from the system, and the chosen value was 1.6.

The pump load will be equal with the maximum pressure developed by the fresh water generator:

$$H_{pump} = p_2 = 3{,}755 \cdot 10^5 Pa$$

$$H'_{pump} = \frac{H_{pump}}{\rho \cdot g} = \frac{3{,}755 \cdot 10^5}{1000 \cdot 9{,}81} = 29{,}773 \text{ mwater}$$

Thus the total flow for the pump feed water system is:

$$Q_{pump} = \frac{Q'_p}{0{,}85} = 17{,}682 \frac{m^3}{h}$$

The viable option regarding a fresh water generator for the water system onboard PCG “Aratos” will be a fresh water generator that ensures the thermal desalination of the salt water, this being produced by the Danish company Alfa Laval. It is a model of a freshwater generator in plates, using steam as a thermal medium. The desalination model is AQUA-65-HWS, with the following technical specifications:

o Number of generators per installation: 1;
o Number of plates: 122;
o Fresh water generation capacity: 30 m3 / h;
o Power supply: 440 V alternating current;
o Frequency: 60 Hz;
o Control voltage: 220 - 230 V;
o Standard of connection to the water network: DIN;

o Hot water flow (for steam): 71.26 m3 / h;
o Suction hot water temperature: 85 0C;
o Hot water temperature on discharge: 74.7 0C;
o Heat consumption: 854.9 kW;
o Pressure drop on the hot water route: 0.15 bar;
o Seawater temperature on suction: 32 0C;
o Sea water temperature on discharge: 51.8 0C;
o Nominal flow of salt water: 35.54 m3 / h;
o Pressure drop on the salt water route: 0.13 bar;
o Steam draft: standard;
o Steam flow: 1332 kg / hour;
o Steam pressure: 6-7 bar.

The figure below shows the distillery on board the LNG tanker ship "Aratos":

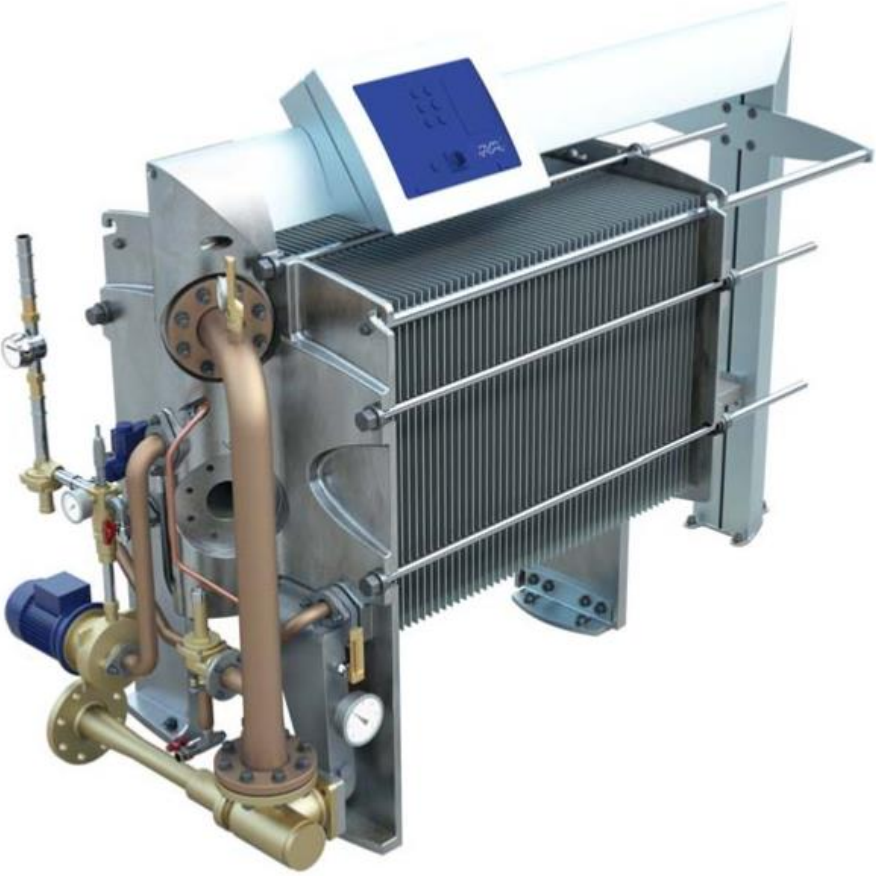

Figure 3: ALFA LAVAL AQUA-65-HWS marine desalinator [3]

That basic operating principles had to be taken into account fresh water will not be generated from polluted seawater sources, while it will not be usable for consumption. Fresh water will be generated when the ship is at a minimum distance of 20 miles from the shore, or when it is away from any shore, to avoid pollution of coastal waters. The maximum ambient temperature at which the system can operate is 50 ^{0}C, while the minimum temperature is 0 ^{0}C. The AQUA-65-HWS domestic distiller can operate in two main modes: the freshwater generator and the water heater.

In the freshwater generator mode, the brine/water ejector is driven by cold water which creates the vacuum needed to reduce the evaporation temperature of the aspirated seawater. Seawater is introduced into the evaporation path through a hole and is distributed on each secondary channel of the plates (evaporation channels). The hot water is then introduced through the secondary channels, thus transferring its heat to the seawater from the evaporator channels.

Once it has reached boiling temperature, it is at a lower pressure than atmospheric pressure, the salt water goes through a partial stage of evaporation and generates a mixture of steam and salt. The brine is separated from the steam and extracted by means of the combined air/brine ejector.

The vessels pass through the separation zone and enter the second plate channel (each channel being composed of 55 plates) from the condensation section. The cooling water is distributed through the other channel and absorbs the heat which is transferred by the steam from the condensing zone. Finally, the fresh water generated is extracted by means of the water pump and pumped to the fresh water tank. The successive stages of operation of the distiller are shown in the images below:

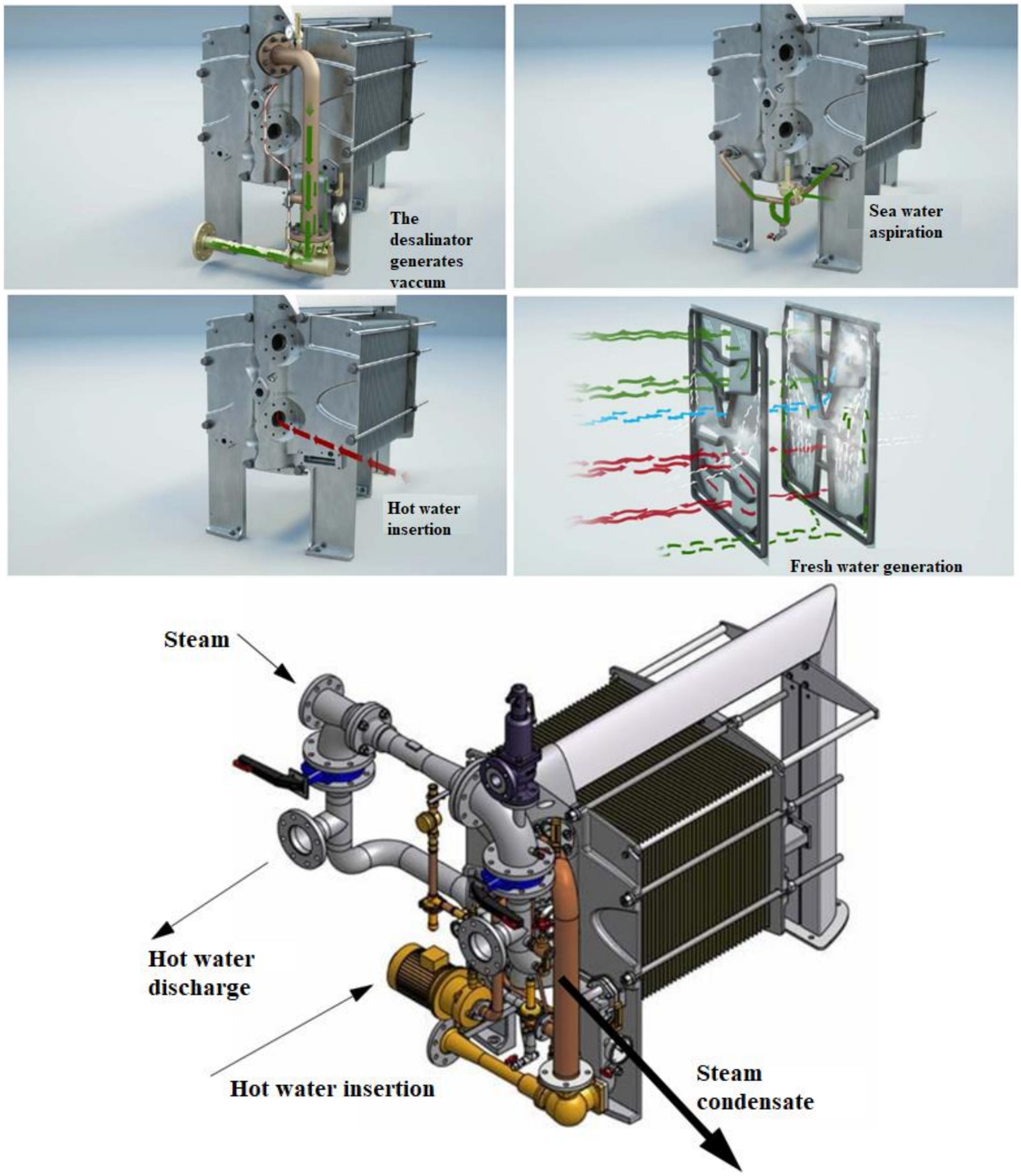

Figure 4: ALFA LAVAL AQUA-65-HWS marine desalinator operation stages [3]

In the operating mode as well as the water heating system, the AQUA-65-HWS distiller uses saturated steam which can be used as the heating medium of the fresh water generator. The saturated steam is fed through the steam injector to the heat exchanger consisting of its plates. In principle, the heating circuit is composed of the circulation system of fresh water in relation to the condensation of the fumes. The steam injector operates in this instance as a recirculation and heating pump for fresh water/steam conduit which comes from the suction branch of the heat exchanger. The generated steam condensate will be released through the piping system on the discharge and will be retransmitted in the water supply tank of the boiler.

4. Conclusions

One of the most important things for a ship to have is access to fresh water that is potable and can be used for cleaning purposes. In recent times, as there has been more of a focus on green shipping and vessels being as environmentally friendly as possible, the use of chemicals needs to be minimized as much as is possible in order to reduce their effects on the environment and promote sustainable water treatment. It is because of this lack of chemicals that constant maintenance of the systems used to produce fresh water needs to be undertaken, or else the systems won't work to their fullest potential. However, even with chemicals, there is a gradual reduction of production capacity within these systems producing fresh water. This is where our innovative products can help.

Systems used to provide fresh drinking water on marine vessels are often found in the shape of evaporators, which evaporates the water into steam which condenses into water that is fit to drink and use for other purposes. These systems need to be kept running constantly in order to filter out the bacteria and organic matter found in sea water, making it suitable for human use. These systems can be treated with chemicals, but this has an environmental impact that many marine companies are trying to avoid. Likewise, as stated, the production capacity for the systems reduces over time, and this means that the systems then have to be dismantled and cleaned thoroughly with chemicals before being used again. One of the major problems associated with these systems is scaling, which occurs when used with mineral heavy seawater which evaporates and leaves behind these minerals.

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