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THE ANALYSIS OF POSSIBLE METHODS OF PROVIDING FRESH WATER FOR SAILING VESSELS BASED ON THE EXAMPLE OF S/V DAR MŁODZIEŻY

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Abstract

In this paper the possibilities of providing fresh water for sailing vessels based on the example of s/v Dar Młodzieży are presented. Different methods of obtaining fresh water such as rainwater harvesting, replenishing water tanks at harbours, collecting condensed water from air conditioning systems or producing fresh water from seawater by means of desalination equipment were considered. Vacuum vaporizers (heated by fresh water used as a cooling medium of the main propulsion engines) and osmotic desalinators (using the phenomenon of reverse osmosis) were being taken under consideration. Special focus was put on the quality of water obtained; comparing the methods mentioned and pursuing the best solution both in technical and economic terms. The choice of desalinators was preceded by the analysis of quantity and configuration of pumps and membranes that will guarantee optimum performance. Selection of the manufacturer was determined by costs of purchase, costs of operation and the availability of spare parts and consumables. The osmotic desalinator ended up as the final choice of fresh water producing device on s/v Dar Młodzieży. Excessive water consumption can be satisfied by replenishing supplies at ports. The paper is concluded with comments and suggestions that can be adapted by a ship owner as a solution for the problem of supplying vessels with fresh water.

Keywords: *sailing vessel, air conditioning system, vaporizer, osmotic desalinator*

1. Introduction

One of the biggest problems related to long sea voyages of sailing vessels was supplying ships with fresh water intended for drinking, preparing meals, sanitary facilities and technical purposes. Wooden hull's structures didn't allow long-term keeping of fresh water supplies in tanks, as it contributed to the growth of bacteria and micro-organisms harmful to human health. What is more, lack of suitable chemical disinfectants and treatment did not favour longer periods of fresh water storage on sailing ships. Undoubtedly applying steel for constructing hulls was a real breakthrough in this matter, it allowed extending storage time of fresh water. However, a long-term sea journeys fail to keep stocks of fresh water for its entire duration and require replenishment. An example of this is s/v Dar Młodzieży where fresh water supplies last for less than 3 weeks.

In this paper authors analysed the possible ways of obtaining fresh water for s/v Dar Młodzieży and pointed out the best economic solution in their opinion.

2. Possible methods of providing fresh water for sailing vessels

There are numerous ways of obtaining and replenishing fresh water for sailing vessels, such as:
- replenishing water tanks at harbours,
- rainwater harvesting,
- collecting condensed water from air conditioning systems,
- using fresh water vaporizers,
- using osmotic desalinators.

2.1. Replenishing water tanks at harbours

Sometimes the capacity of all fresh water tanks on sailing ships is not sufficient to meet the demand for fresh water during voyages. For instance, on s/v Dar Młodzieży the capacity of all (two) fresh water tanks is approximately 338.1 m^3 and with nearly 200 people embarked the potable water supplies last for about 15-20 days. In addition, carrying large amount of fresh water on the ship involves ensuring the proper quality (freshness) of water, e.g. by maintaining adequate cleanliness of tanks and water treatment (higher temperature leads to faster growth of bacteria, including faecal *Escherichia coli*).

Supplying ship with fresh water exclusively in ports involves relatively high expenses. Tab. 1 summarizes the average price of one cubic meter of fresh water in selected harbours in the first half of 2013.

Tab. 1. The average price of fresh water in selected ports in the first half of 2013

	Port	Country	Price		Converted to PLN	Additional remarks
1	Gdynia	Poland	12.95	PLN	12.95	
2	Copenhagen	Denmark	36	DKK	20.22	Connection fee 260 DKK
3	Bilbao	Spain	1.5-1.8	€	6.28-7.53	
4	Mumbai	India	150	INR	4.75	
5	Rotterdam	Netherlands	8	€	22.81	Not less than 5m3
6	Naples	Italy	1.81-2.30	€	7.58-9.63	Connection fee 11.60 €, 360 €/h for barge
7	Riga	Latvia	2	€	8.37	Not less than 15m3
			4.5	€	18.83	
8	Ras Al Khaimah	UAE	35	AED	3.99	
9	Valencia	Spain	2.42 - 3.12	€	10.13-13.06	Not less than 25m3 and additionally 36.94 €/h
10	Klang	Malaysia	9.0-12	RM	9.52-12.69	
11	Mombasa	Kenya	4	$	13.03	
			8.5	$	27.68	
12	Broome	Australia	3.73	$	12.15	
13	Beirut	Lebanon	4	$	13.02	Not less than 48$
14	Belfast	Northern Ireland	1.76	£	8.7	44 or 99 £ connection fee
15	Keelung	Taiwan	45	TWD	4.89	Equipment included in price
			80	TWD	8.7	
16	Southampto	England	1.37 -	£	6.77-7.56	Fixed charge 61.98-76.86 £
17	Houston	USA	1.25-2.77	$	4.07-9.02	
18	Astoria	USA	1.75	$	5.7	Connection fee 100 $
19	Galati	Romania	1.73	LEI	1.64	
			Average price		10.88	

According to the information presented in Tab. 1, the lowest price of 1m^3 of potable water is about 1.64 PLN (in the Romanian port of Galati), while the highest price in Rotterdam reaches 23 PLN. Average price of one cubic meter of drinking water in seaports amounts to around 11 Polish Zlotys (excluding extra charges such as connection fees, fixed charges or equipment rental). Additional fees, in the case of small vessels, may double average price of 1m^3 of fresh water.

2.2. Rainwater harvesting

Theoretically, it is possible to obtain significant quantities of rainwater on a sailing vessel. The global, mean precipitation over 30 years was 2.67 mm/day (Fig. 1). Accordingly: between April and September, the average rainfall for the area of the Baltic and North Sea are 2-3 mm/day, Mediterranean Sea is about 0.5-2 mm/day and for the Atlantic Ocean range from 0.5-9 mm/day (depending on the area). On s/v Dar Młodzieży (with sail area about 2936 square meters) by using sails for harvesting rainwater it is possible to recover approximately 8 tons of water a day.

So far, rainwater harvesting does not seem to be viable, because it requires special drainage systems on sails that involve substantial investments. However, this issue is worth considering.

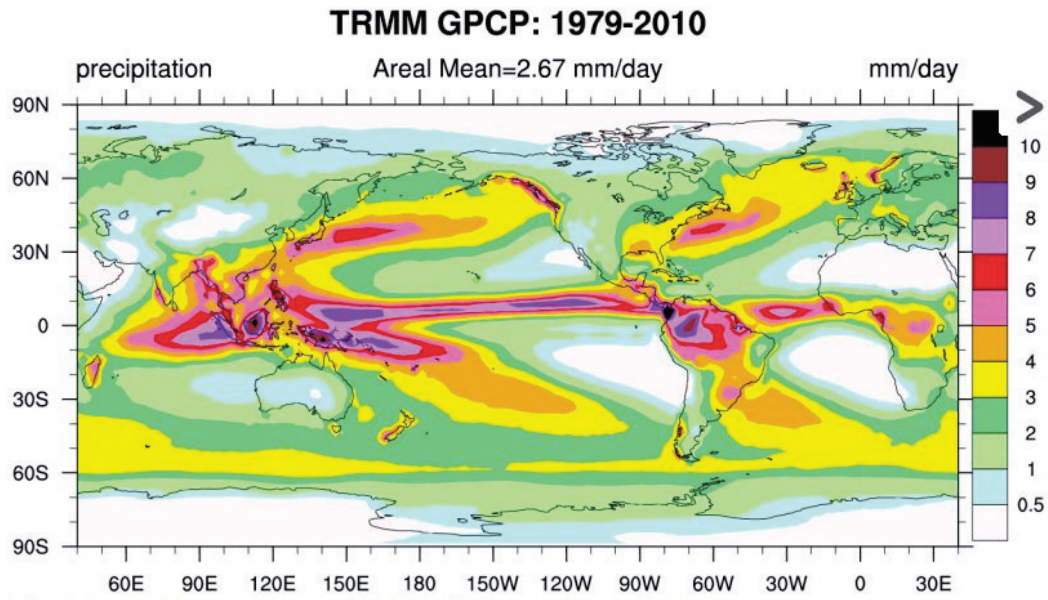

Fig. 1. Climatological annual mean precipitation (mm/day) for 1979-2010 [6]

2.3. Collecting condensed water from air conditioning systems

Air conditioning is the process of altering air in the room aimed at maintaining selected climatic conditions such as sufficient purity, range of temperature and humidity to ensure favourable conditions for operation of the human (terms of comfort) or the optimal conditions for a defined industrial process (e.g. operation of machinery, equipment and fittings).

S/V Dar Młodzieży is equipped with three air conditioning units, whose task is to provide required parameters of air. Fig. 2 shows schematic layout of the air-handling unit including description of installed equipment.

In the summer, the air outside usually has got higher absolute humidity than the air inside. As a result of cooling process the vapour condenses in the air-conditioning unit, which instead of being removed overboard, may partially cover the demand for engine room water. When travelling in warm and tropical regions it is possible to recover on s/v Dar Młodzieży (from all three air-handling units) about 500-1000 litres of fresh water, useful mainly for technical purposes.

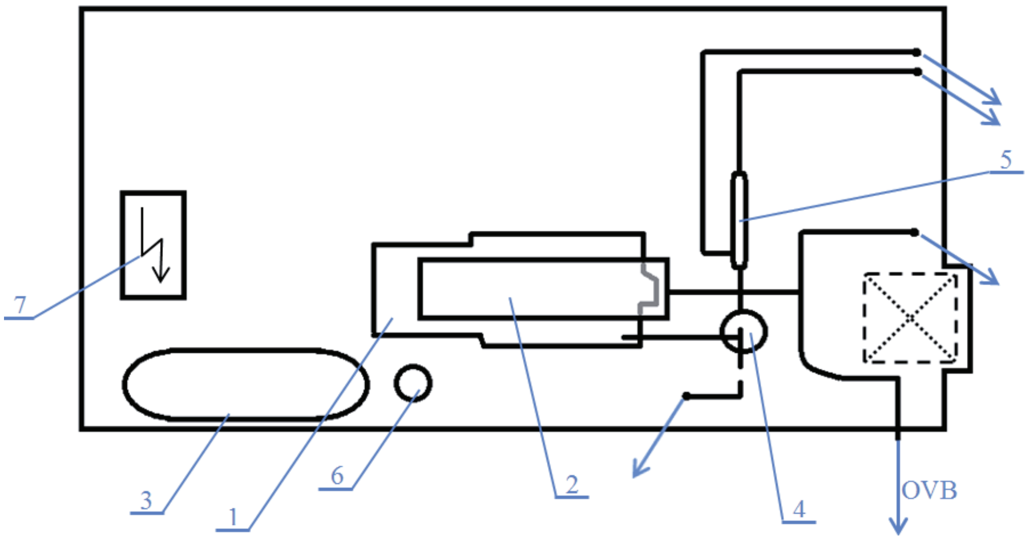

Fig. 2. Schematic layout of the air-handling unit at s/v Dar Młodzieży 1 – compressor unit; 2 – tubular condenser; 3 – freon tank; 4 – sea water pump; 5 – regenerator; 6 – strainer; 7 –compressor's control panel; OVB – overboard

2.4. Fresh water generators

Fresh water generator (also called evaporator or distiller) is a device used for production of fresh water from sea water by application of evaporation process (distillation). Working principle of fresh water distiller is based on evaporation of sea water and then condensation of generated vapour. The following media can be used in the evaporation process: steam, water and electricity. In a case of water heated evaporators, fitted on ships propelled by reciprocating internal combustion engines, fresh water that cools down main propulsion engines is used as a heating medium. This type of distillers is installed on majority of vessels. The usage of hot water from cooling systems lowers ship's operating costs [1].

Evaporators are primarily used for the production of technical water for cooling systems, feeding steam boilers or electrolyte refilling. However, the resulting fresh water surplus can be used for sanitary purposes. Salinity of fresh water, depending on its purpose, varies from 2 to 200 ppm, while the salinity of sea water is about 35 000 ppm.

It can be assumed that vacuum fresh water evaporators are exclusively installed in today engine rooms. Reducing the pressure lowers the temperature of the water evaporation to 41-44^{o}C, while the absolute pressure in vacuum evaporators is 0.007-0.009 MPa. Besides obvious energetic reasons, so much lower temperature prevents intensive salt deposits on heat transfer surfaces (that occurs in the temperature above 48^{o}C). Thus vacuum evaporators can be cleaned rarely (2-3 times a year). On the other hand, such a low boiling point cannot guarantee appropriate bacteriological water properties [3].

On s/v Dar Młodzieży two vacuum evaporators WY63 shown on Fig. 3 were installed (built in Marine Equipment Factory in Rumia between 70's and 90's) with maximum production of 6.3 tons of fresh water a day. All construction elements such as evaporation chamber (1) with tubular heater, tubular condenser (2), demister (3) and other auxiliaries, piping and fittings are mounted in frame construction.

Due to the application of tubular heat exchangers WY evaporators occupied a lot of space in the engine room. Furthermore, a small power of main engines and especially their withdrawal from work during the cruise under sails caused that these evaporators were used occasionally and derived amounts of fresh water were much smaller than capabilities of these devices (about 1 ton a day). Therefore, in 1991 it was decided to dismantle and remove both distillers from the engine room.

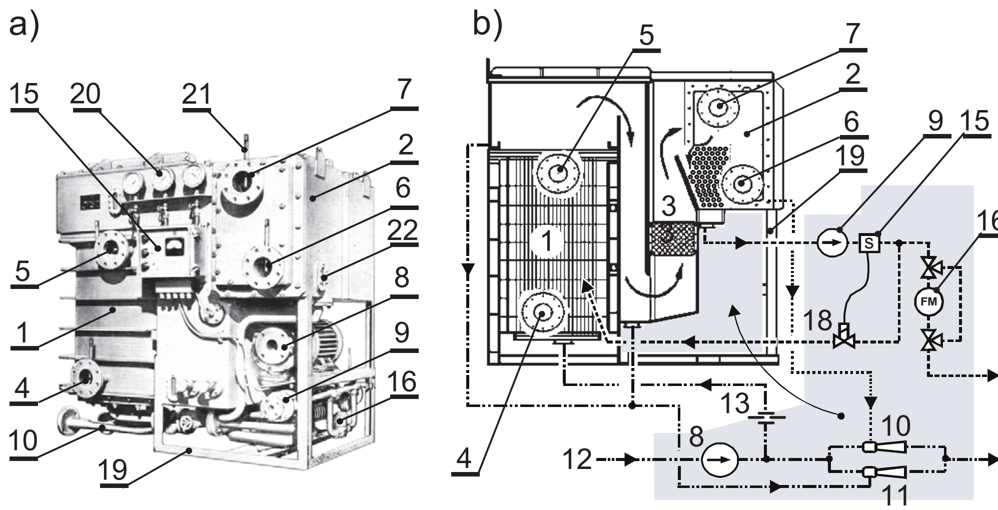

Fig. 3. Fresh water generator FUO Rumia type WY [2] a) general view, b) section and working system, 1 – evaporation chamber; 2 – condenser; 3 – demister; 4 – heating water inlet; 5 – heating water outlet; 6 – cooling water inlet; 7 – cooling water outlet; 8 – ejector pump; 9 – distillate pump; 10 – air ejector; 11 – brine ejector; 12 – sea water inlet; 13 – orifice; 14 – sea water overboard outlet; 15 – salinometer; 16 – distillate flow-meter; 17 – distillate outlet; 18 – solenoid valve; 19 – frame; 20 – manometer; 21 – thermometer; 22 – sight glass

2.5. Osmotic desalinators

Osmosis is a natural process of diffusive (spontaneous) movement of solvent molecules through a semipermeable membrane into a region of higher solute concentration. The process stops when the hydrostatic pressure of liquid column (h) will offset osmotic pressure differences. The phenomenon is shown in Fig. 4.

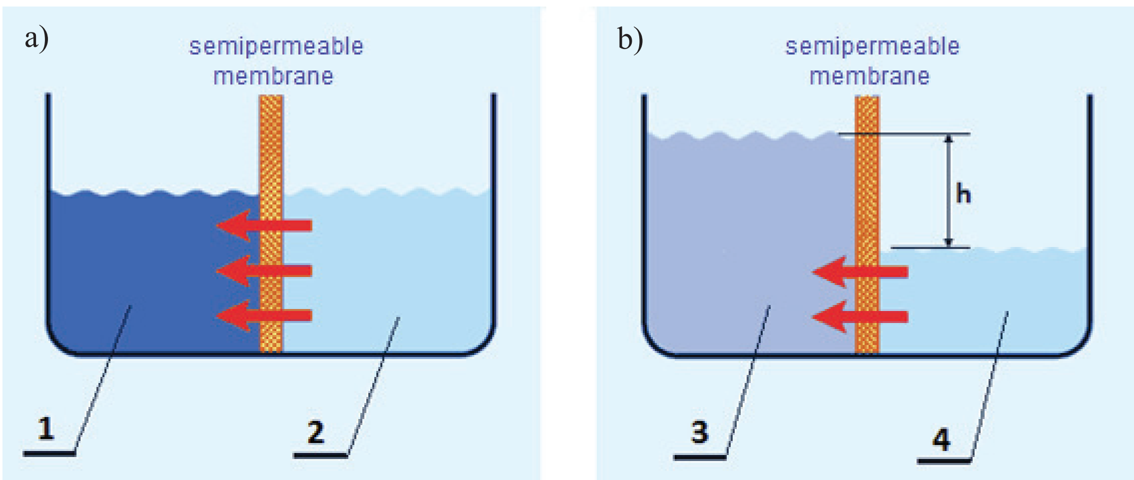

Fig. 4. Mechanism of osmosis phenomenon [5] 1 – sea water; 2 – fresh water; 3 – sea water with higher concentration of salt; 4 – fresh water with higher salt concentration a) beginning of the process b) end of the process

Applying sufficiently large external force (P), increasing the pressure in the liquid with a higher concentration of solution (sea water) will reverse the flow direction. The amount of fresh water will increase, while the amount of seawater (1) will be reduced and its concentration will rise – a by-product of the reverse osmosis process is brine. A similar phenomenon will occur when the temperature on both sides of the membrane will vary. The phenomenon of reverse osmosis is presented in Fig. 5.

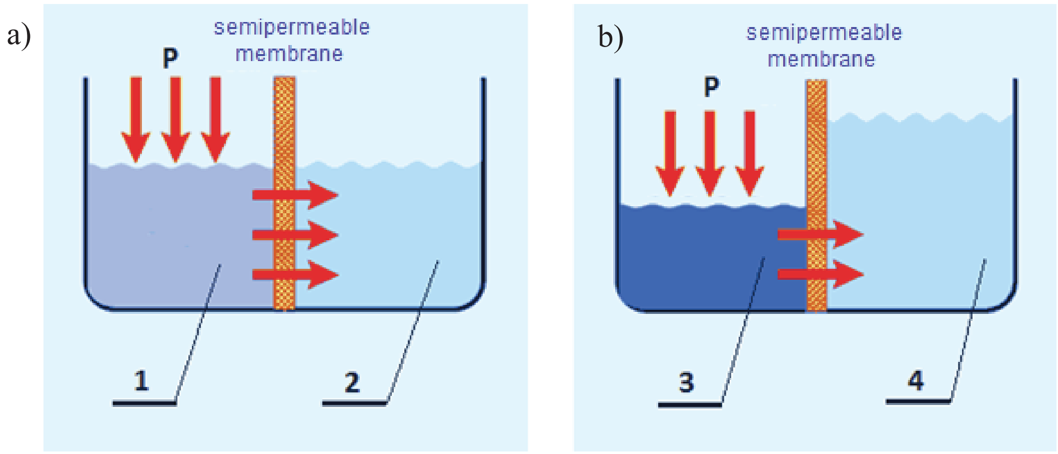

Fig. 5. Mechanism of reverse osmosis phenomenon [5] 1 – sea water; 2 – fresh water; 3 – sea water with higher concentration of salt (brine); 4 – fresh water a) beginning of the process b) end of the process

The average salinity of fresh water produced in the osmotic desalinators is 200-500 ppm, which is suitable for sanitary facilities and drinking. These devices are also able to produce engine room water with a salinity of less than 20 ppm at the expense of the delivery rate.

The yield of the sea water desalination process reaches up to 35% relatively to the feed water flow and deteriorates with increase of salinity and decrease of temperature of sea water.

Osmotic desalinators practically only need electric energy necessary to power feed pumps (usually centrifugal) and high pressure pump that ensures maximum discharge pressure up to 10 MPa [3].

Reverse osmosis desalinators are offered in series and have the output from few hundred litres to several hundred m^3 per day.

In 90's s/v Dar Młodzieży was fitted with Sea Recovery SRC SW/S1/V osmotic desalinator (Fig. 6). Depending on the amount of installed membranes this device provides daily fresh water production from 3 to 15 tons.

Applying dead-end pre-filters enforces their frequent, expensive replacements (once a week or every 200 hours of operation), that is why the production of fresh water using this device is unbeneficial. In addition, installed membranes allow recovering only 8% of flowing water.

High operating costs caused that this desalinator was operated on s/v Dar Młodzieży less than 3000 hours.

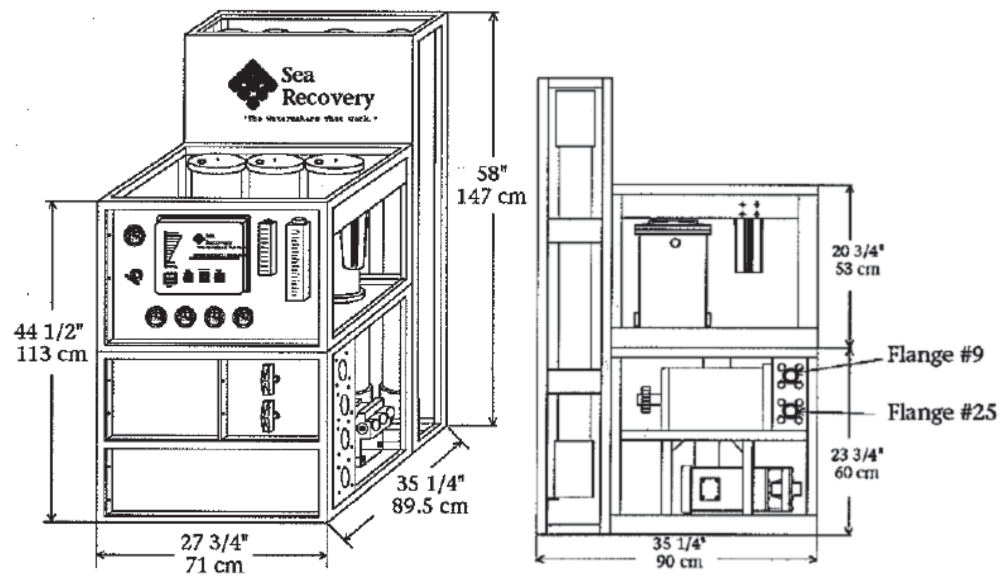

Fig. 6. View and dimensions of SRC SW/S1/V desalinator [7]

Prototypical desalinator DOE Pelican installed on s/v Dar Młodzieży seems to be the solution for the problem of supplying the vessel with fresh water (Fig. 7).

Thanks to cross-flow filtration (ultrafiltration) the cost and complexity of filters operation have been kept to a minimum. Moreover, installed Liqui-Flux W10 ultrafiltration membrane (being able to treat up to 250 m^3 of water per day) makes possible to upgrade this device to achieve much greater output. No need to replace the filter cartridges and low cost of chemicals (used to clean the membrane) evoke very low production costs of fresh water.

Fig. 7. Prototypical DOE Pelican desalinator installed on s/v Dar Młodzieży (phot. Adam Kasprzak) [4]

According to a logbook of s/v Dar Młodzieży DOE Pelican desalinator equipped with two SW30-2540 membranes (the smallest offered configuration) produces averagely 2.7 tons of fresh water a day.

3. Remarks concerning the solution for the problem of supplying s/v Dar Młodzieży with fresh water

Based on the analyses it was found that upgrading DOE Pelican osmosis desalinator is the best solution for the problem of supplying s/v Dar Młodzieży with fresh water both in technical and economic terms.

According to performed simulations it was decided to expand this device up to six SW30-2540 membranes (two branches with three membranes connected in series, each branch supplied by a separate HP pump CAT 247). The cost of upgrading this device was estimated to be about 15.5 thousand PLN. The average daily output of expanded osmosis desalinator should reach about 10.62 m^3 of fresh water what allows to extend ship's endurance up to 41 days (average daily water consumption reaches 18.8 m^3 and capacity of all fresh water tanks is approximately 338.1m^3).

The cost of producing 1 m^3 of fresh water by DOE Pelican desalinator (after upgrades) has been estimated at about 5 PLN. Regular usage of this device (for obtaining fresh water) would reduce annual expenditure for sanitary water for about 11 365 Polish Zlotys. Taking into account expenses for spares, consumables and maintenance costs of modernization will be balanced in approximately two years.

After consultations with representatives of the manufacturer and analysing technical documentation it was concluded that some parts of Sea Recovery desalinator (such as pumps, high pressure hoses and 4” x 40” membrane pressure housings) can be re-used during expanding DOE Pelican osmotic desalinator.

Another possible adaptation is supplying Sea Recovery desalinator bypassing expensive dead-end pre-filters with water from DOE Pelican’s ultrafiltration membrane. In this case it will be necessary to create a new pipeline connecting two desalinators (that requires creating a pass through a watertight bulkhead under supervision of the classification society) or relocating one of these devices. What is more, membranes not used for years will probably need to be replaced.

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