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An experimental study of a newly designed freezing desalination unit equipped with reversed vapor compression cycle

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A R T I C L E I N F O

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A B S T R A C T

A newly designed freezing desalination system was constructed. The system operates on the principle of reversed vapor compression. It is equipped with two identical heat exchangers, one of them works as an evaporator and the other as a condenser. A three-way valve was used to reverse the operation of heat exchangers, causing the ice in the evaporator to melt. The performance of the newly designed system was evaluated in both the forward and the reversed cycles. Electric current, power consumption, pressure drop, water productivity, and specific consumption were all investigated. The experiments were conducted with ice ratios of 0.27, 0.39, 0.45, 0.54, and 0.65 with cycle operating periods of 110, 135, 180, 240, and 300 min. The results showed that the electrical current, power consumption, and pressure drop were decreased with the reversed cycle. The maximum energy-saving percentage was 13% for cycle operation time 300 min. The amounts of freshwater reached 19 L for cycle operation times of 300 min from 30 L saline water. It is recommended to run our newly designed system at an ice ratio of 0.45 since these results save 1.5% in the reversed cycle, which is the most used cycle in the new design.

1. Introduction

Desalination refers to the process of separating salt from saline water to produce fresh water for humans. There are various desalination methods vary according to their sensitivity to heat or pressure. The thermal desalination is based on evaporation and condensation process (e.g., multi-stage flash (MSF) and multiple effect distillations (MED)). The pressure is used to purify water using membrane desalination, such as electrodialysis (ED), reverse osmosis (RO), and forward osmosis (FO). Although membrane desalination provides for around 73% of the global market compared with 27% for thermal methods [1]. However, membrane desalination consumes more energy than conventional methods of freshwater treatment [2]. As Williams et al. [3] emphasized that the RO produces more concentrated brine, which is detrimental to the environment. Kadi et al. [4] proved that the FD process consumes less energy than thermal desalination. Additionally, they stated that FD eliminates the need for sophisticated and expensive chemical pre-treatment processes, such as membrane desalination.

According to the aforementioned reasons, several studies were conducted to design a more efficient desalination system. Recently, freezing Desalination (FD) has emerged as one of the most promising approaches due to its ability to overcome the challenges and limitations associated with membrane or thermal techniques [5]. In comparison to the membrane and thermal techniques, one of the

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advantages of FD is that it is less sensitive to fouling problems that block membrane desalination processes [6]. Although the initial cost and energy consumption of FD are significantly higher than those of membrane desalination, the expense of maintaining the membrane more than compensates for this difference [7]. Because of the lower operating temperatures, FD is not susceptible to corrosion and scales formation problems compared to thermal desalination. The FD is a low-cost desalination technology comparing to other desalination methods as [8]. The FD process is divided into direct and indirect FD. The first is the direct FD process, which involves direct contact of the refrigerant with saline water. The refrigerant enters the crystallizer and absorbs heat from saline water and vaporizing. Simultaneously, the temperature of saline-water declined, and nucleation occurred [9]. The direct FD process outperformed the indirect process with a larger surface area and higher heat transfer coefficient. Moreover, it is more economically efficient [10]. The main difference between direct and indirect FD is that the crystallizer wall separates the refrigerant from the saline water. Its advantage is that it generates refrigerant-free water, which is essential for defining the future utilization of produced water [4].

Shmroukh et al. [11] designed identical Ranque-Hilsch vortex tubes (RHVT) for the seawater desalination. The desalinated water quantity increased by around 79% of the initial seawater quantity for the series hot vortex tubes arrangement. Furthermore, Hyein Shin et al. [12] studied the performance of a self-nucleation cyclic freezing desalination unit utilizing the surface scraped freeze crystallizer unit. The 'U' shape stirrer is used to crush, and fragment scaled ice. They discovered that irrigation water with 2000 ppm concentration may be used for washing using 50% of water at 16 °C. With TDS concentration of 1757 mg/L, the system productivity achieved over 40% with through two cycles of FD within 4 h of total operational time. Attia [13] proposed a freezing desalination unit based on the reversed heat pump principle, which overcomes the problem of ice treatment and handling observed in conventional desalination systems. The ice block was washed and melted in the same tank as the ice formed. An energy and economic analysis of the system was performed, showing that the cost of producing one litter of freshwater is lower than other desalination techniques. Moreover, Han et al. [14] made a successive washing treatment with 274.15 and 277.15 K freshwater with different amounts of washing water to increase the salt removal efficiency. Xie et al. [15] designed a Jacketed cylinder equipped with nozzles (leaned at 45 °C) and air diffusers. Their design made a spiral flow of the refrigerant, thereby more turbulence occurred, and heat transfer was promoted.

Miyawaki et al. [16] performed a tubular ice system along with several aluminum cylinders that have treated the solution and added to the crystallizer. In addition, they found that more efficient tubular ice was observed at slower ice growth and higher circulation rates. Fujioka et al. [17] prepared a 52 mm of diameter cylindrical vessel where ethylene glycol at −20 °C was circulated. Their work indicated that the optimum working condition was the ice-front speed of 0.5 cm/h and a stirring velocity of 1.45 m/s. Htira et al. [18] reduced acetone content in water using a vertical stainless-steel wall immersed in a cylindrical tank. Eisenbart et al. [19] successed to purify water from glycerol using stainless-steel cold finger inside a 600 ml double-walled beaker. Furthermore, Zambrano et al. [20] designed a system with a comprised refrigerated plate, a thermally insulated chamber, and a cylindrical jacketed vessel. They could reach a salt removal efficiency up to 98.5%. A crystallizer installed with a sparger on the top and equipped with a circulator bath was tested by Jiang et al. [21]. Hasan and Louhi-Kultanen [22] used prefeeding to work with natural freezing in regions where ambient temperatures drop below 0 °C during the wintertime. While Cao et al. [23] used Liquefied natural gas (LNG) as a cold energy source. Abdelrahman et al. [24] made exergy and parametric study for freeze desalination with Reversed vapor compression cycle. Dehghani et al. [25] made an experimental analysis of brine recirculation in the humidification-dehumidification desalination of saltwater. Kariman et al. [26] performed an energy and exergy study of evaporation desalination system using a mechanical vapor compression system. Jayakody et al. [27] made a parametric analysis and compared it with CFD (Computational Fluid Dynamics) model to find out the impacts of the initial salinity of saltwater and freeze tube temperature on freshwater production. However, Badawy [28] achieved two times less salt concentration when the melted ice water produced by using partial crystallization of

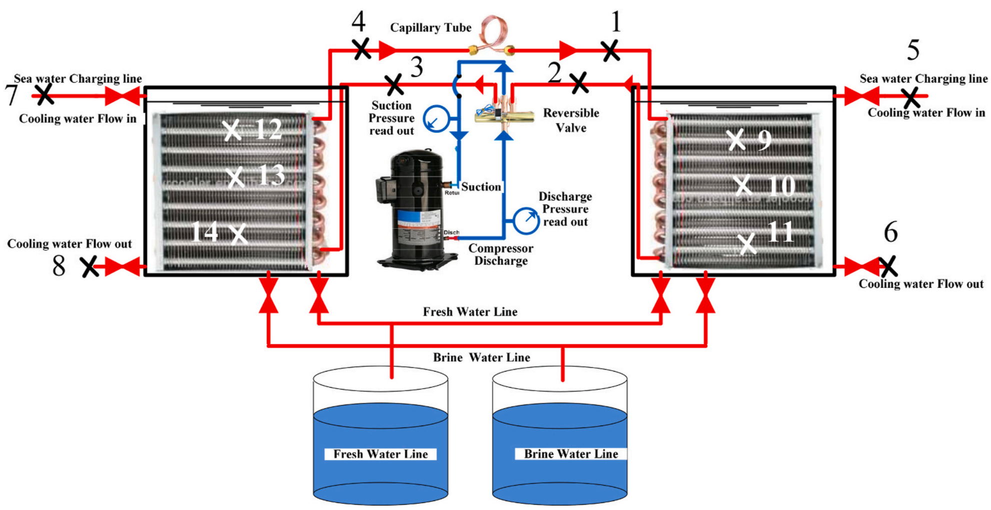

Fig. 1. A schematic diagram of the designed freezing water desalination unit using a reversed vapor compression refrigeration cycle.

single-stage freezing. Eghtesad et al. [29] investigated that the effect of different values of heat flux, hydraulic diameter, initial salt concentration, and freezing time on the ice salinity and ice formation speed numerically. Zhang et al. [30] made experiments that reduced about 60% salinity gradient.

According to our assessment and that of Kalista et al. [5], the application of freezing desalination has a high potential for development. The current work aims to design, build, and test a new system to produce freshwater using the freezing desalination method. The deigned system is depending on using a heat pump that switches heat flow between two identical tanks (evaporator and condenser). After the design process, the system was checked carefully, and its performance shown. Then, the ice that formed in the evaporator during the heat pump operation phase was used to enhance the heat pump cycle's performance in the next phase of the operation. Based on our review and that of Kalista et al. [5], no available data about an experimental investigation of such system. Testing the performance of the current system was performed with a clear technique. The methodology used in the current research is a solid scientific method that based on freezing and science desalination. The authors believed that the current work has a significant impact on the future of desalination. This work has a remarkable effect on filling the gap between Egypt and developed countries in terms of access to safe drinking water. Companies can invest to take advantage of the benefits of the outputs of this research.

2. Designed system

The test rig used in the current work is shown in Figure (1). It consists of a compressor, condenser, evaporator, capillary tube, reversible three-way valve, and two tanks. R-22 was used as a refrigerant in the freezing circuit. Both the freshwater and brine water tanks are connected to the evaporator and condenser. Throughout the experiment, seawater with (35000 ppm) is tested. The power of the used compressor is one hp. The condenser and evaporator consist of copper tubes with aluminum fins. They were put in a heat insulation tank. Two similar rectangular tanks were fabricated from clear acrylic used for containing heat exchangers, which were used as evaporators and condensers in the refrigeration unit. There are two holes from the top and the bottom of each tank used as source and drain for the water used in the process of cooling the condenser. The used capillary tube diameter and length are 0.012 and 4.1 m, respectively.

Different measurements were used in the present work. The suction pressure and delivery side of the refrigeration unit circuit was measured by two pressure gauges. The gauges were placed as one in the suction of the compressor and the other at discharge. The current and voltage of the compressor were measured with two multimeters. Also, the power consumption during the operation was calculated. Thermocouples were used to find out the temperatures as following: five thermocouples were installed inside each tank to track ice formation. Two thermocouples for the water inlet and outlet temperature for each tank. Two for the refrigerant inlet and outlet temperature for each tank and finally one thermocouple for ambient temperature. Readout temperature devices are used to record the different thermocouple temperatures. A multimeter was used to measure the electrical current.

3. Practical steps

The practical steps for the current research are divided into two-cycle. Firstly, the forward cycle, then a reversed cycle. In the beginning, liquid water existed in both evaporator and condenser. After that, in all cycles ice formation at the evaporator heat exchanger and melting of ice in the condenser heat exchanger. Ice Figure (2) illustrates the growing up of sample on the cooling coil. Details about cycles are explained as follows:

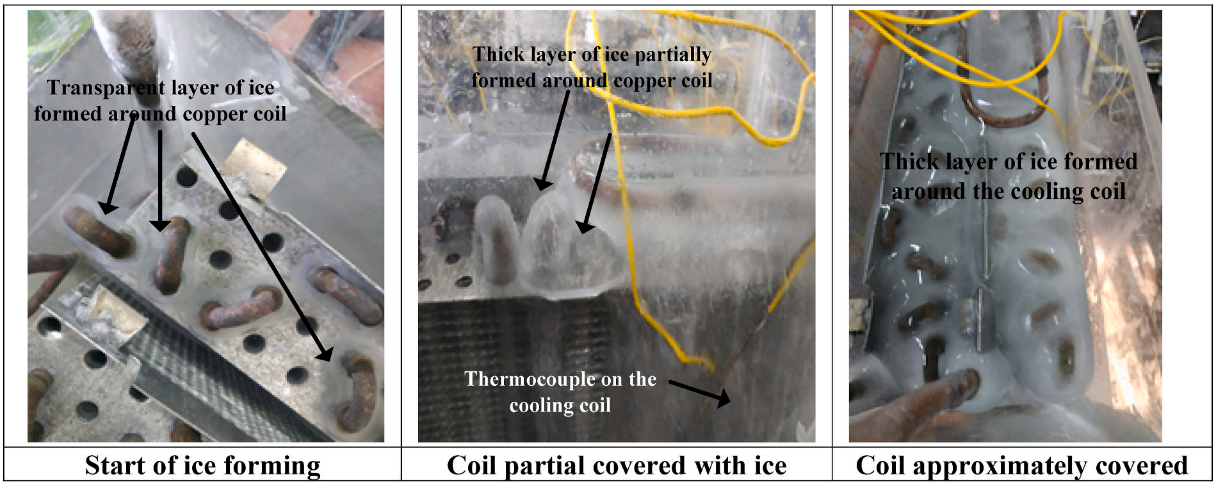

Fig. 2. Ice grows up of a sample on the cooling coil.

3.1. Forward cycle

Water with 35000 ppm was used to fill the tank that services as an evaporator-ice formation tank which is considered as the heat pump source. The cooling water was allowed to fill the other tank-condenser tank, which is considered as the heat sink for the heat pump and allowing the water to flow with the previously calculated value, which keeps the water in the tank at 25–30 °C. The condenser is cooled with the flow of water. The operating unit continues to run for a specified period of time that could be adjusted to achieve a desired icing ratio. At the end of the estimated time for the ice ratio to complete, the compressor is switched off, and the brine water (not frozen) is drawn from the evaporator tanks and leaving a block of ice in the tank. Then wait for some time to rest the compressor. During this period, the condenser tank will be filled with seawater (35000 ppm) in preparation for the following cycle of operation as an evaporator. Drain the formed brine water (water with high salinity that formed in the evaporator tank). Additionally, the washing process was done for the ice that formed in the evaporator tank.

3.2. Reversed cycle

Before starting the compressor, the reversible valve was turned on to reverse the cycle, effectively switching operation phase of the tanks from evaporator to condenser and vice versa. The ice that was formed on the coils of the previous cycle used to raise the COP of the heat pump cycle. After a certain period, the ice block melts completely. After that, the melted ice-distilled water is withdrawn from the tank and weighted to ensure that the whole ice amount is melted completely. The cooling process started to be performed with running water. The cycle was repeated (reversed mode), so distilled water can be reproduced in every cycle. One of the strengthening points of the current idea is the repeatability and continuous production of distilled water.

4. Calculation equation

The compressor Power was calculated using:

$$P = I \times V \quad [\text{Watt}] \tag{1}$$

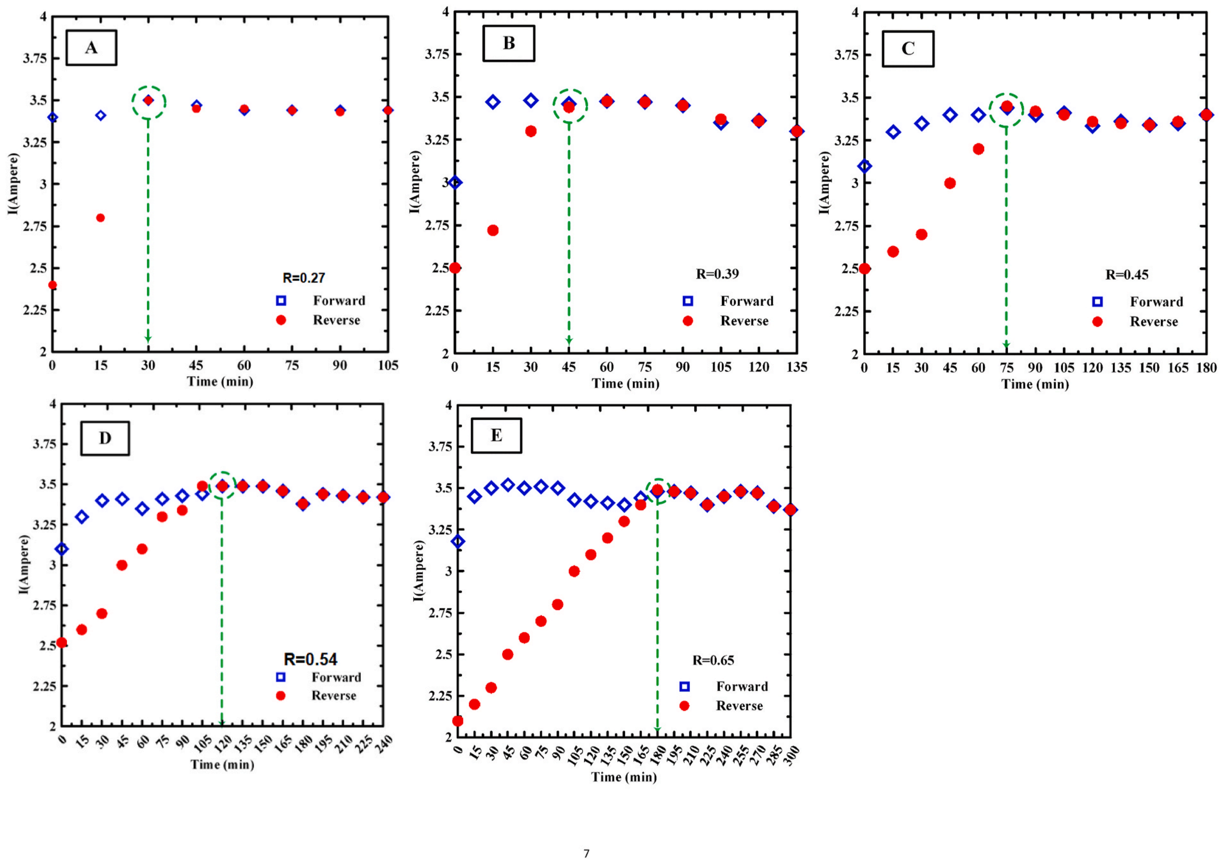

Fig. 3. Compressor electric current during the operation period in forward and reversed operation at various icing ratios. (A) R = 0.27, (B) R = 0.39, (C) R = 0.45, (D) R = 0.54, and (E) R = 0.65.

Energy consumption per unit mass production of freshwater can be calculated using the equation below:

$$\text{specific energy consumption} = \frac{E\ (\text{watt}) \times \text{time}\ (\text{hr}) \times 60 \times 60}{1000 \times\ m_{fresh}(\text{littre})} \quad [KJ/kg] \tag{2}$$

Water productivity was calculated using:

$$\text{water productivity} = \frac{m_{fresh}(\text{littre}))}{\text{time}\ (\text{hr})} \quad [kg/hr] \tag{3}$$

The saved energy percentage can be calculated as:

$$\text{Saved energy percentage}\ (\%) = \frac{E_{Forward} - E_{reserved}}{E_{Forward}} * 100\% \tag{4}$$

5. Results and discussion

The next section evaluates the performance of the proposed system. The electrical current was measured for different ice ratios. The studied ice ratios were 0.27, 0.39, 0.45, 0.54, and 0.65. The recording reading period was done every 15 min. The ice ratio or the amount of ice formed around the coil, was controlled by adjusting the total time of compressor operation. The power consumed during the freezing cycle was figured out. The pressure drop between input and output was indicated. After that, Energy consumption and energy saving percentage during operation time for forward and reversed cycle at different ice ratios was investigated. The water productivity for the forward, reversed cycle, and the drop in productivity at different ice ratio was given. Then the specific energy consumption for different ice ratios and the percentage of change was expressed.

5.1. Electrical current

The performance of the cycle is measured by the amount of current retrieved by the compressor. This is because the applied voltage is almost constant. Thus, recording the current during the operation of the cycle will be a good indicator of the cycle's power consumption. Figure (3) shows the compressor current for the complete cycle including forwarding and reversed. The compressor current is drawn against time for different ice ratios. According to Fig. 3, for the forward cycle, the electrical current is nearly constant during the experiment. Although the current increased for the reversed cycle, this increase stops at a certain time, and the value became constant for the rest of time nearly equal to the values of the forward cycle. That point can be determined as equalization time. The period before equalization time increases with the increase of the quantity of ice around the coil (ice ratio), which is correlated with the operation time of the forward cycle. This equalization time was 30, 45, 75, 120, and 180 min for formed ice ratio 0.27, 0.39, 0.45, 0.54, and 0.65, respectively. Based on the results, the reversed cycle always starts at low current consumption. This is because of the ice formation on the coil that works as an evaporator from the previous cycle of operation (forward cycle), which reduces the high pressure of the cycle. Hence, the newly designed techniques presented in the present paper helps to decline the electrical current used in the freezing desalination system.

5.2. Power consumption

In the freezing cycle, electrical power is used to run the compressor, and this power is the primary input for the cycle. It can be calculated based on equation (1). Throughout the presented work, the voltage is constant, so the power consumed depends on the current. Figure (4) shows the power consumed over the time for the reversed cycle at different ice ratios. Results are fitted in the polynomial third order equation as it gives less error for the curve fitting. The polynomial equations for power consumption over the

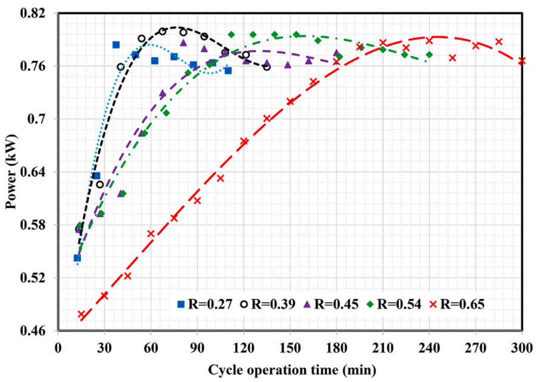

Fig. 4. The power consumed for the reversed cycle through the operating time at different ice ratios.

time at different ice ratios are given in Table 1. The fitted curves show that the power for all ice ratios follows the same trend. Power increases until it reaches the equalization time and then becomes constant. Moreover, more ice ratio means more equalization time. It can be found that when the ice ratio increases, the consumed power needs longer times before reaching the equalization time. Therefore, it means that the total energy consumed is affected by the operation time of the forward cycle by which the quantity of ice formed around the coil increases or decreases. Finally, it could be concluded that the more forward cycle operating time increases, the more ice formed around the coil. After reversing the cycle, the coil severed as a condenser (heat sink). Hence, it kept the heat sink at a low temperature, i.e., it needed low power to deliver heat through it. The higher the quantity of ice increases, the longer the time to reach the highest level of consumed power.

5.3. Pressure drops

Fig. 5 shows the pressure drop that should be overcome by the compressor at different ice ratios during the operation of the forward cycle and reversed cycle. The pressure drop between input and output indicated that the compressor needed to maintain the required pressure difference between the evaporator and condenser for the cycle. It could be taken to indicate how much energy (%) has been saved when the reversed cycle was used. The pressure drop is given with third-order polynomial equations, which are presented in Table 2.

5.4. Energy consumption and energy-saving percentage

Generally, when the designed system reduces energy consumption, it is worth being built because energy consumption is a core factor for determining any system efficiency. Hence, energy consumption for the presented new design for the freezing desalination system was investigated. This examination results are shown in Figure (6). The energy consumption in the case of the forward cycle is 5137 kJ at 110 min, and it was increased to be 6330, 8340, 11160, and 14240 kJ for a cycle operation times of 135, 180,240, and 300 min, respectively. While the results for the reversed cycle were 4804, 6000,7785,10483, and 12393 kJ for the same cycle operation times, respectively. The energy consumption for the reverse cycle was less than the forward cycle at all cycle operation times. It is worth knowing that the forward cycle, where liquid water is found at the condenser since it is an ordinary freezing cycle, only happened once at the beginning of the work. However, the reversed cycle, where ice is found at the condenser coil, is repeated all times after one forward cycle. Therefore, the newly designed system will save energy compared with the conventional freezing desalination system, which works as the forward cycle. The saved energy percentage is the difference between the energy consumed in the forward cycle and the reversed cycle to the energy consumed in the forward cycle, expressed as ratio. It can be calculated as given in equation (4). Energy consumption and energy saving are shown in Figure (6). The maximum achieved energy-saving percentage was 13% for cycle operation time 300 min, while for other times was around 6%. The reserved cycle consumes less power as ice on the condenser reduces the temperature and pressure of the compressor outlet. Hence, the saved energy increases with the increase of ice ratio due to the existence of ice for a long time before its completely melting.

5.5. Water productivity

Any desalination system aims to produce distilled water with a low concentration of salt. The best system is the most productive freshwater system. The total amount of saltwater is 30 L. The rate of freshwater productivity is sacculated as equation (3). The amount of freshwater produced in forward and reversed cycles at different ice ratios (cycle operation time) is shown in Figure (7). According to Figure (7), ten litter of freshwater is produced in the forward cycle with a cycle operation time of 110 min and an ice ratio of 0.27. The amount of freshwater produced was increased to 13.4,15.3, 19, and 24 L for cycle operation times of 135 min (R = 0.39), 180 min (R = 0.45), 240 min (R = 0.54), and 300 min (R = 0.65), respectively for the forward cycle. However, for the reversed cycle, the amounts of freshwater produced were 7.8, 12.5, 14.5, 16.5, and 19 L for the same cycle operation times and R values, respectively. Results show that the more the ice ratio, the more the freshwater productivity due to the increase in quantity of formed ice with ice ratio for both forward and reversed cycles. At the same ice ratio, the reversed cycle was lower in the productivity of freshwater for the forward cycle. The lowest difference between productivity of forwarding and reversed cycle occurs at 0.39 and 0.45 ice ratios. The productivity of the forward cycle is greater than that of the reversed cycle when running simultaneously, although the efficiency of the cycle is increased by using ice formed on the coil as a heat sink for the condenser section. The explanation for this phenomenon is that the system component uses a capillary tube to create throttling. Thus, a certain pressure should be created in the condenser section to keep the quantity of Freon's flow high enough to absorb heat from the heat source. This is due to the constant pressure drop through the

Table 1
The polynomial correlation for power consumption with time at different ice ratios.

Cycle operation time (min)	Power consumed (kW)
110	$= 1E\text{-}06t^3 - 0.0003t^2 + 0.0189t + 0.3372$
135	$= 4E\text{-}07t^3 - 0.0001t^2 + 0.0126t + 0.4119$
180	$= 7E\text{-}08t^3 - 4E\text{-}05t^2 + 0.0057t + 0.476$
240	$= 3E\text{-}08t^3 - 2E\text{-}05t^2 + 0.0045t + 0.4931$
300	$= -2E\text{-}08t^3 + 2E\text{-}06t^2 + 0.0019t + 0.4433$

Table 2
The polynomial correlation for pressure drop with time at different ice ratios.

Cycle operation time (min)	Pressure drops (psi)
110	$= 0.0003t^3 - 0.0704t^2 + 4.6508t + 104.31$
135	$= 0.0003t^3 - 0.0654t^2 + 5.0499t + 72.915$
180	$= 6E\text{-}05t^3 - 0.0253t^2 + 3.3417t + 60.865$
240	$= 3E\text{-}05t^3 - 0.0143t^2 + 2.0198t + 105.01$
300	$= 1E\text{-}05t^3 - 0.008t^2 + 1.3493t + 133.64$

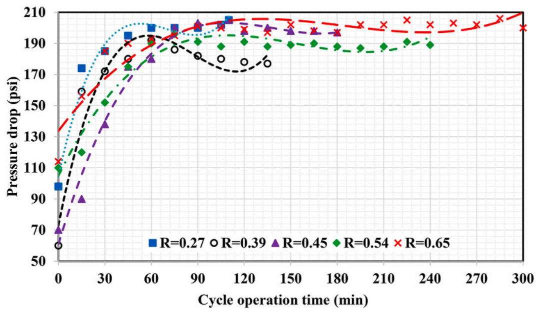

Fig. 5. Pressure drop measurements around the compressor during the forward cycle.

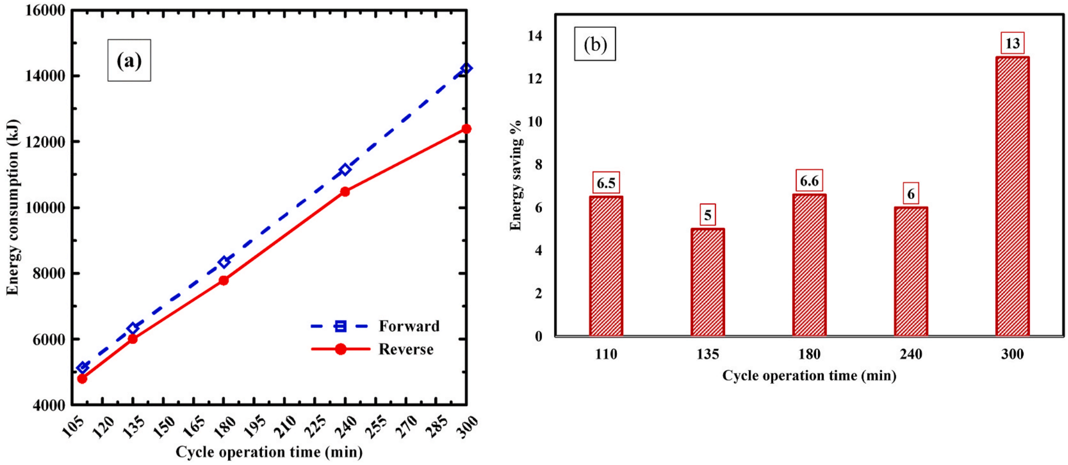

Fig. 6. (a) Energy consumption, (b) the percentage of energy savings during operation time for forward and reversed cycles at different ice ratios.

capillary. When the ice is formed on the condenser section, it lowers the pressure inside the condenser section, which means the amount of Freon flow is lower than the required to remove the heat from the condenser section. Consequently, the quantity of ice formed on the evaporator section in the reversed cycle will be lower than the forward cycle at the same operation time.

5.6. Specific energy consumption

The specific energy consumption is the electric energy consumed per unit mass production of freshwater. It clarifies how much energy is required to produce 1 kg of freshwater. The lower values of specific energy consumption refer to a well-designed system and more acceptable techniques. The specific energy consumption can be calculated applying equation (2). Figure (8) illustrates the specific energy consumption and specific energy saving for the forward and reserved cycle at different ice ratios and the percentage of change. It was found that the ice ratio of 0.27 has a higher specific energy ratio comparing with ice ratios of 0.39 and 0.45.

The reason for that is that the ice ratio of 0.27 has lower water productivity compared with 0.39 and 0.45, as shown in Fig. 7. The highest values of the specific energy ratio were found for ice ratios of 0.54 and 0.65, respectively, as they have the maximum amount of freshwater produced. It was found that the reserved cycle has higher the specific energy consumption for all studied ice ratio cases expected the values around 0.45. The saving in the specific energy consumption is 1.5% for the ice ratio of 0.45. The specific energy consumption is decreased between the ice ratio of 0.27 and the ice ratio of 0.39 and then starts to increase with the ice ratio increases.

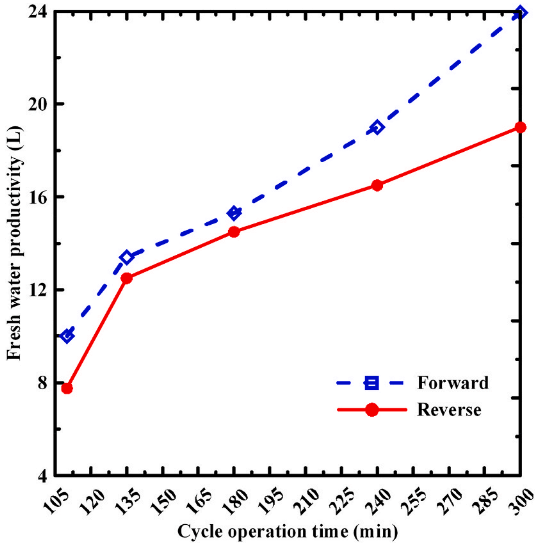

Fig. 7. Water productivity for the forward and reversed cycle at cycle operation time.

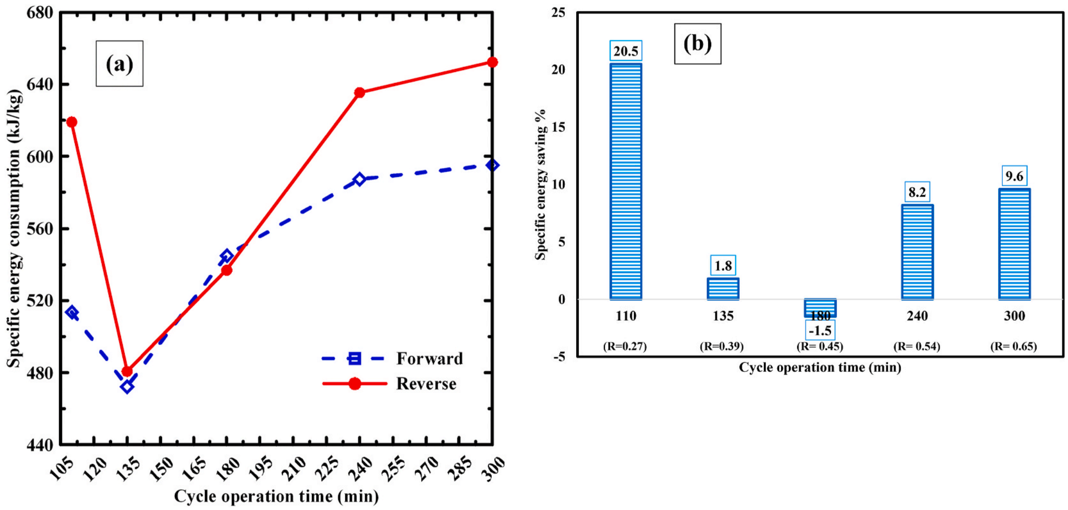

Fig. 8. (a) Specific energy consumption (b) specific energy saving for forward and reserved cycles at various ice ratios and cycle operating times.

The explanation for that behavior is that the more ice ration increases, the thicker the ice layer, which increases the total resistance of the layers to removing heat, which means the rise in work required to deliver the heat to the condenser section of the cycle. Hence, balancing ice ratio, distilled water productivity, and electrical power consumption is needed. According to our results, it is recommended to work with an ice ratio of 0.45 for our newly designed system as it makes saving with 1.5% in the reversed cycle, which is the most used cycle in the new design.

6. Conclusion

A new design of freeze desalination using a reversed heat pump system was developed. The new system is considered a trend for seawater desalination, with many advantages over other desalination systems. Throughout the experiments, the system was run with two types of cycles; forward and reserved. The system includes a reversible three-way valve that can convert between the heat source and heat sink as heat exchangers. The forward cycle could be considered traditional freezing, while the reversed cycle could be considered another system that uses the ice formed to raise the efficiency of the cycle. In the case of the reversed cycle, the electrical power consumption was lower than in that of the forward cycle. In addition, the pressure drop was reduced in the reversed cycle because of the presence of ice on the condenser section. According to our findings, the more ice there is, the longer time it takes to reach the highest level of consumed power. It could be interpreted as measuring how much energy was saved when the reversed cycle was used. The relationship between electrical power consumption and pressure drop with cycle operation time was depicted graphically and mathematically in equation form.

The energy consumption value in the case of the forward cycle was 5137 kJ at 110 min. It got up to be 6330,8340, 11160, and 14240 kJ for a cycle operation times of 135, 180,240, and 300 min, respectively. While the energy consumption values for the reversed cycle were 4804, 6000,7785,10483, and 12393 kJ for the same cycle operation times, respectively. For a cycle operation time of 300 min, the maximum energy-saving percentage was 13%. The forward cycle produced more freshwater than the reverse cycle. Ten litter of freshwater was generated in the forward cycle with a cycle operation time of 110 min and an ice ratio of 0.27. Freshwater production for the forward cycle raised to 13.4,15.3, 19, and 24 L for cycle operation times of 135 min (R = 0.39), 180 min (R = 0.45), 240 min (R = 0.54), and 300 min (R = 0.65), respectively. For the reversed cycle, productivity of freshwater was 7.8,12.5,14.5,16.5, and 19 L for the same cycle operation times and R values, respectively. Or results revealed that the specific energy for ice ratio of 0.27 is greater than the ice ratios of 0.39 and 0.45 because the ice ratio of 0.27 has lower water productivity than the ice ratios of 0.39 and 0.45. However, the specific energy consumption for the reserved cycle was less than the forward cycle for the ice ratio of 0.45. According to our findings, working with an ice ratio of 0.45 is recommended for our newly designed system because it saves 1.5% in the reversed cycle, which is the most used cycle in the new design.

Authorship statement

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Analysis and/or interpretation of data: Ahmed A. Altohamy, M.A.Sharafeldin, M. A. Abdelrahman, Ahmed A. A. Attia.
Drafting the manuscript: M.A.Sharafeldin, Ahmed A. Altohamy
Revising the manuscript critically for important intellectual content: Ahmed A. Altohamy, M.A.Sharafeldin, M. A. Abdelrahman, Ahmed A. A. Attia, Ismail M.M. Elsemary.
Approval of the version of the manuscript to be published (the names of all authors must be listed):

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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