Research Article

Application of new series connection scheme of vortex tubes in seawater desalination unit using new vortex generators

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Abstract
In this work, an experimental study on new series connection of two Ranque-Hilsch vortex tubes with new vortex generator materials, potential in seawater desalination was implemented, this combined modification has not been studied in open literature. Polycarbonate and Polyamide-Nylon 6 were tested and compared as new vortex generator materials that enhance the heat transfer between the two air streams inside the vortex tube. Moreover, using new seawater preheater by utilizing the waste heat in the exit air stream from the last vortex tube in the arrangement. The results revealed that the hot fraction of both arrangements should be kept at 0.5 for optimum vortex tubes series connection performance. Moreover, the modified series arrangement with Polycarbonate generator had higher evaporator main hot temperature and lower condenser main cold temperature than that of the modified series arrangement with Polyamide-Nylon 6 generator. Furthermore, the desalinated water percentage of Polycarbonate generator connection and Polyamide-Nylon 6 generator connection were reached about 94% and 89%, respectively. Therefore, the modified series hot connection of Ranque-Hilsch vortex tubes with Polycarbonate based vortex generator is recommended for use in seawater desalination applications.

Keywords Performance · Series vortex tubes · Seawater desalination · Vortex generator material

Abbreviations

CAD	computer-aided design
COP	coefficient of performance
FDM	fused deposition modeling
HF	hot air mass fraction
MPA6	modified arrangement with PA6 vortex generator
MPC	modified arrangement with PC vortex generator
PA6	Polyamide-Nylon 6
PC	Polycarbonate
RHVT	Ranque-Hilsch vortex tube
RO	reverse osmosis
SHVT	series hot vortex tubes configuration
TDS	total dissolved solids

List of symbols

D	inner diameter of the vortex tube[m]
i	number of measured values [–]
L	length of the tube [m]
N	number of nozzles [–]
n	set of measured values [–]
R	determined value [–]
$\overline{X}$	mean of the measured values [–]
X	measured value [–]

Greek symbols

δ	Uncertainty [–]
σ	standard deviation [–]
ΔT	temperature difference between main hot and cold airstreams [C]

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1 Introduction

Worldwide seawater desalination became a valuable solution for providing potable water for communities and industrial development, as it turned into the most sustainable water resource alternative. More than fifty percent of the desalination plants were constructed in the Mideast and Arab Gulf region, where freshwater shortage and available conventional power sources. The major currently used desalination technologies are thermal-based desalination and membrane-based desalination, while an enormous amount of experimental and theoretical works have been focused on both desalination technologies in the open literature, however, these technologies need more interest and modifications. For thermal desalination techniques, Shafii et al. [1] theoretically and experimentally examined a solar desalination system based on heating seawater using evacuated tube collector. They developed a mathematical model to evaluate their system performance, which provided good agreement with the experimental results, they also found that freshwater production was increased to 0.83 kg/h with using the evacuated tube. Zuo et al. [2] analyzed experimentally and numerically seawater desalination system using solar chimney, for combined electricity and freshwater production. They indicated that their proposed combined system improved effectively the freshwater production and solar desalination efficiency, particularly to reach about 9.805 ton/h and 16.73%, respectively. Another solar thermal-based desalination system was investigated experimentally by Zhao et al. [3], their system was consisted of multi-stage humidification and dehumidification solar desalination system. Their results showed that freshwater production was adopted to be more than other conventional solar thermal-based technologies with water yield of up to 63 kg/h. However, Xu et al. [4] experimentally analyzed solar heat pump desalination system based on humidification and dehumidification process. They estimated that the maximum freshwater productivity was reached about 12.87 kg/h, moreover, their system productivity was increased by 15.51% in contrast to single-stage humidification and dehumidification system, with reducing the costs by 17.36%. Another technique was improved by Cao et al. [5], they conducted a theoretical analysis on freeze seawater desalination system using liquefied natural gas. Their model results showed that 2 kg/hr of ice meltwater could be obtained by using cold energy of 1 kg/hr of liquefied natural gas.

While for membrane desalination techniques, Fuwad et al. [6] reviewed forward osmosis desalination based on biomimetic membranes. They deduced that while naturally forward osmosis function of Aquaporin, Aquaporin biomimetic membranes could be successfully used in desalination applications due its high productivity of 4.2 kg/h, with an increase in desalination efficiency by non-biological and biological components integration. On the other hand, Turek et al. [7] assessed experimentally the gypsum scaling and the energy consumption of four different desalination systems, the first was single-stage reverse osmosis system (RO), the second was hybrid RO–electrodialysis system, the third was hybrid RO–nanofiltration system and the fourth was hybrid RO–electrodialysis–nanofiltration system. They concluded that their proposed fourth system was able to produce almost saturation concentrated brine, which could be further used in the Chlor-alkali industry or in evaporated salt production. Moreover, Emadzadeh et al. [8] fabricated novel thin-film nanocomposite RO membranes, by embedding different quantities of titanate nanotubes into polyamide layer, also, the antifouling properties and the separation performance of the nanotubes were investigated. They found that the thin-film nanocomposite which embedded with 0.05% titanate nanotubes attained separated water flux of 93% higher than other control thin-film one, while for organic fouling tendency during the RO process, it also exhibited the highest tolerance. Furthermore, Ihsanullah [9] reviewed the application and the synthesis progress of carbon nanotube membranes for water purification and desalination, such discussed carbon nanotube membranes were vertically aligned, bucky paper and mixed nanocomposite ones. Ihsanullah [9] mentioned that bucky paper carbon nanotube membranes could produce up to 12 kg/hr. Moreover, it can be concluded that the carbon nanotube membranes with further research will have a shiny outlook in water desalination technology.

A combined mechanical and thermal-based desalination system was studied by Shmroukh et al. [10], they experimentally evaluated the performance of novel desalination system, employing both hot and airstreams of Ranque-Hilsch vortex tube (RHVT), to evaporate seawater and condensate the produced vapor, respectively. RHVT working principle was based on splitting the inlet compressed air into two hot and cold influxes, by the forces created by the vortex generator inside RHVT [11] as shown in Fig. 1. Their outcomes depicted that the proposed system desalinated water production was found to reach up to 68% of the initial seawater quantity. Moreover, the total dissolved solids (TDS) of the produced freshwater didn't exceed 480 mg/l.

Furthermore, a numerical study investigated by George Stanescu [12] on the potential of using compressed air or methane from single RHVT to produce potable water. Their simulated system results showed that under compression

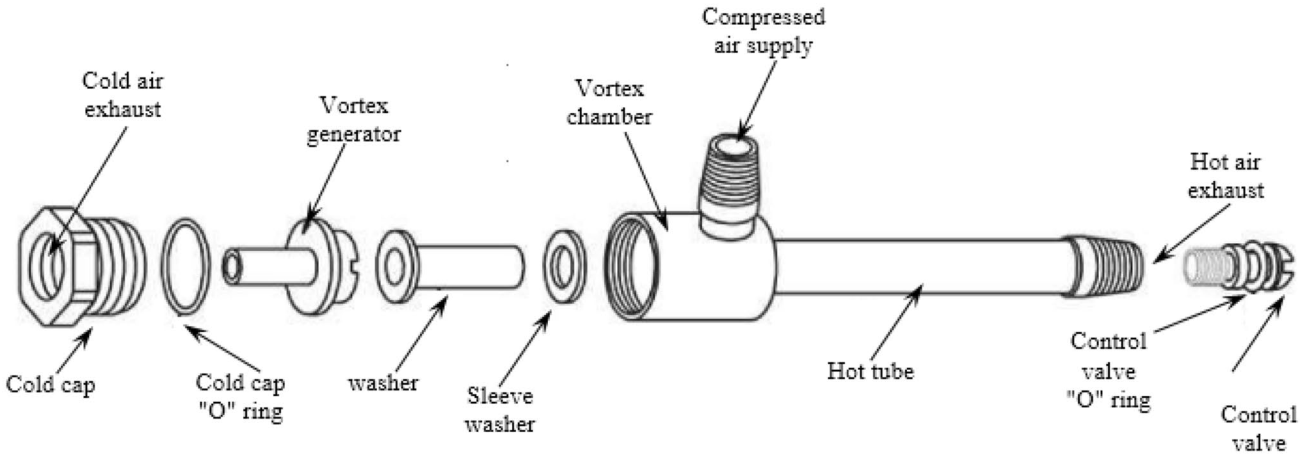

Fig. 1 Schematic of the main components of counterflow RHVT [11]

pressure range of 3 to 7 bar the produced potable water could reach 0.005 to 0.012 kg for each 1 kg of the compressed gas flowing to RHVT. Moreover, the system high performance was given by using methane rather than air. On the other and, Shmroukh et al. [13] developed new RHVTs simple arrangements to increase the system desalination efficiency and overall performance. Their results demonstrated that using simple series hot vortex tubes arrangement (SHVT) increased the desalinated water production to reach up to 79% of the initial quantity. Another application for RHVT was the system implemented by Kartashev et al. [14]. They used high-pressure steam to enter the RHVT of the water treatment unit, then it was split into hot steam and cold vapor [14]. They reported that their developed system could eliminate the scaling formation in water boilers and pipelines.

On the other hand, regarding the RHVT standpoint side, the development and changing of vortex generator materials were studied in different research papers. Kirmaci et al. [11] analyzed experimentally the performance of RHVT with Fiberglass, aluminum, and steel as vortex generator materials, with 2, 3, 4, 5, and 6 as the number of vortex generator nozzles. They derived that aluminum and steel had supplied maximum temperature gradient. Also, as the vortex generator number of nozzles increased as the temperature gradient decreased. Kaya et al. [15] investigated experimentally parallel RHVTs under brass, polyamide plastic, and aluminum vortex generator materials, with 2, 4, and 6 vortex generator nozzles number. Their developed study results revealed that at an inlet pressure of 550 kPa, aluminum vortex generator with 6 nozzles had obtained the maximum RHVT performance. Moreover, Kaya et al. [16] studied their later system of [15] but with 2, 3, 4, 5, and 6 as the number of vortex generator nozzles. They concluded that while taking into consideration both of coefficient of performance (COP) values, exergy analysis, heating and cooling capacity, and the temperature difference, the optimum performance was obtained with aluminum vortex generator with 6 nozzles. While, Kirmaci and Kaya [17] reviewed the effect of vortex generator nozzles number and materials, working fluid, and RHVT connection type on RHVT performance. They found that the air was the most effective working fluid in all studies, while 3 and 4 nozzles of the vortex generator produced the best RHVT performance. However, further investigations are necessary to be done to examine different parameters' effects. Furthermore, Cebeci et al. [18] analyzed experimentally the effect of aluminum and polyamide plastic vortex generators with varying the inlet pressure from 150 to 700 kPa on RHVT performance. They concluded that the maximum temperature gradient was obtained at an inlet pressure of 700 kPa for aluminum RHVT. Also, energy separation in transparent RHVT is examined by Xue et al. [19]. They implied that the central free vortex flow which affected the energy transfer through vortex tube flow streams has a great impact on vortex tube performance and efficiency. Moreover, Syed et al. [20] investigated numerically the energy separation in RHVT. They reported that the energy separation at both cold and hot ends was better in case of using air as a working medium [21] rather than hydrogen. On the other hand, the performance of RHVT could be optimized and the energy was saved in case of using ejector with the RHVT as reported by Lagrandeur et al. [22].

Subsequently, depending on the above literature survey, using RHVT in seawater desalination system is an auspicious technique, however, it needs more development due to its high electrical energy consumption, low desalinated water production compared with other conventional desalination systems. Moreover, one of the most important drawbacks of the previous schemes of RHVT/desalination systems is that their used vortex generators had low energy separation between the two air streams inside the vortex tubes. Hence, the novelty of the current study is found in two main concepts. First, using two new thermoplastic materials in the vortex generator manufacturing, which lead to better energy separation and acceptable vortex generator performance, by helping on reducing the unwanted radial heat flows from the peripheral to the axial vortex inside the wall and increasing the radial temperature gradient near the swirl device, which leads to enhance the efficiency of the vortex tube. Second, improving the target RHVT based desalination system performance by evolving a new series hot RHVTs arrangement equipped with new seawater preheater to preheat the seawater before entering the evaporator using the excess and waste heat of the exit air stream from the last vortex tube in the configuration, that air stream was treated as disposal and lost without any use in the previous schemes. While there were no accomplished studies on such combined modifications in the open literature.

2 Materials and method

2.1 Experimental test rig

In this study, two identical RHVTs were used in series hot arrangement with three tanks, one new tank for seawater preheating, the other for seawater evaporation (evaporator), and the third for freshwater vapor condensation (condenser), as shown in the photograph of Fig. 2.

Detailed schematic of the desalination system is presented in Fig. 3. The setup is consisted of two identical RHVTs arranged in series with new configuration, the used RHVTs had two identical vortex generators with 25 mm in diameter, 35 mm in length and 1.3 mm nozzle groove depth, while, the hot tube had a length (L) of 150 mm and a diameter (D) of 7.5 mm, moreover, the vortex chamber inner and outer diameters were 25 and 35 mm, respectively, with a length of 50 mm, moreover, the inner diameter of the air inlet tube was 7.5 mm and the diameter of the cold orifice was 8 mm. While the vortex generator had 3 nozzles (N) as maintained by [13]. A compressor was maintained at 4 bar to generate the main

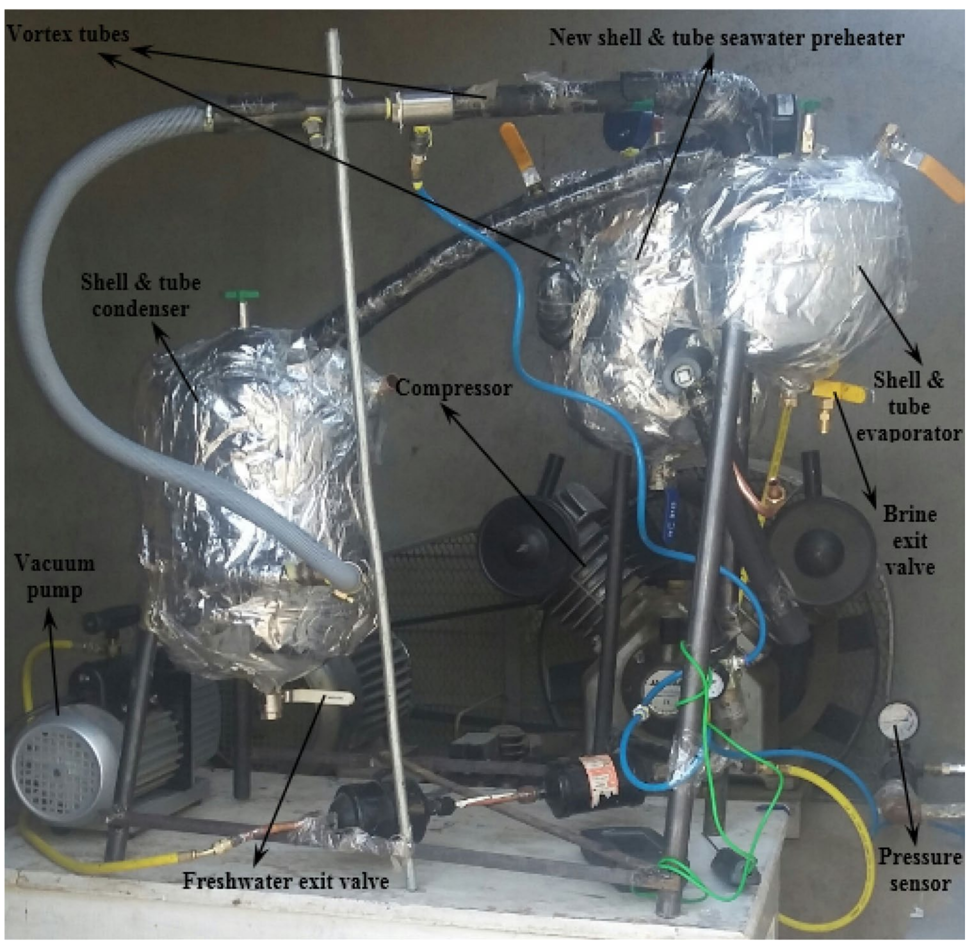

Fig. 2 Photograph of the proposed desalination setup

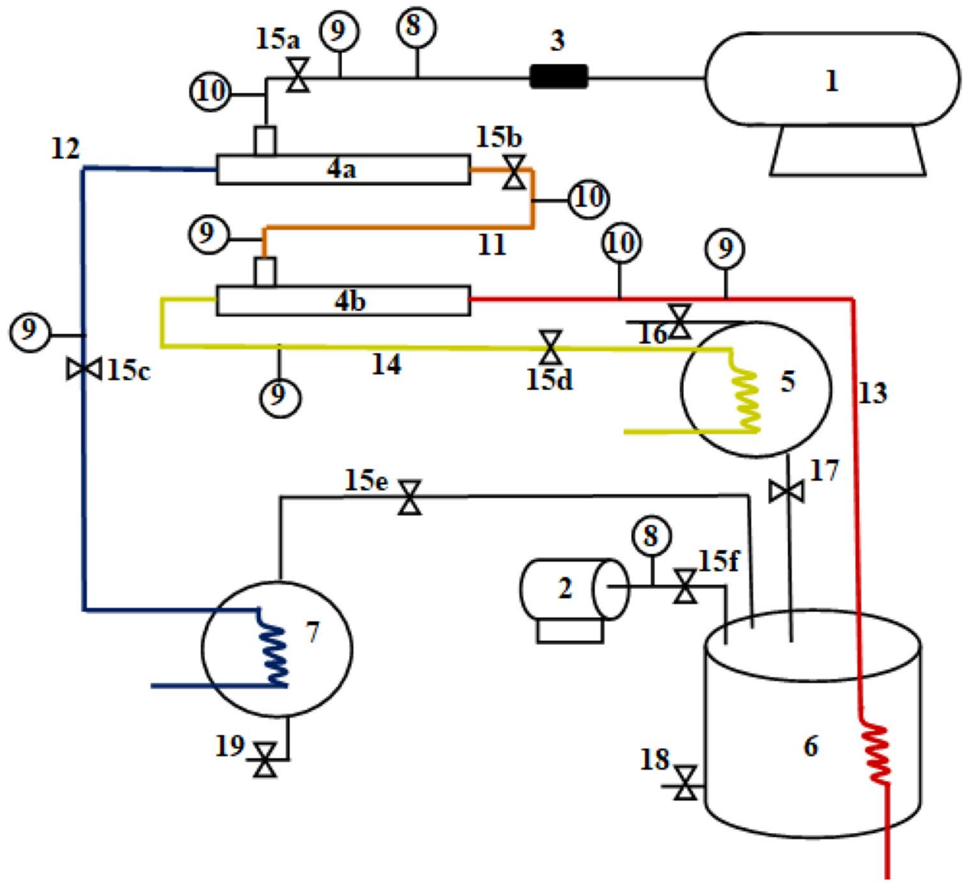

Fig. 3 Schematic for the test rig with the new arrangement. (1) Air compressor, (2) Vacuum pump, (3) Filter dryer, (4) Ranque-Hilsch vortex tubes, (5) Seawater preheater unit, (6) Seawater evaporator unit, (7) Condenser unit, (8) Pressure sensors, (9) Temperature sensors, (10) Flow rate sensors, (11) Hot air line, (12) Main cold air line, (13) Main hot air line, (14) Relatively cold air line, (15) Control valves, (16) Seawater inlet valve, (17) Preheated seawater inlet valve, (18) Brine exit valve, (19) Freshwater exit valve

compressed airstream, which entered the first RHVT and split into extremely cold (main cold) and hot airstreams. The extremely cold airstream entered to the shell and tube condenser to condense the desalinated water vapor, whereas the hot airstream of 3.2 bar pressure entered the second RHVT, then split into relatively hot and extremely hot (main hot) airstreams. The relatively hot airstream was still higher in temperature than the seawater inlet temperature, therefore, the relatively hot airstream was entered the new shell and tube seawater preheater tank, allowing seawater to preheated before entering the evaporator to decrease the amount of energy needed to evaporate the seawater. While the extremely hot air was entered the shell and tube evaporator allowing more water vapor to be generated, whereas the vacuum pump was used to decrease the seawater evaporation temperature. Furthermore, two different new materials for the vortex generator in RHVTs were used and tested, the first material was Polycarbonate (PC), while the second was Polyamide-Nylon 6 (PA6). The new vortex generators were manufactured by using computer-aided design (CAD) and the fused deposition modeling (FDM) printer.

A photograph describing both vortex generators' material is shown in Fig. 4. For PC vortex generators the modified RHVTs arrangement is called modified series hot vortex tube with PC vortex generator (MPC), while for PA6 one, the arrangement is called modified series hot vortex tube with PA6 vortex generator (MPA6), the thermophysical properties of these two vortex generator materials are shown in Table (1).

The main aim of the present work is to study the effect of the new vortex generators and the new RHVTs arrangement on the enhancement of the desalination system performance. Using a fixed amount of 2000 ml of seawater in each experiment, the seawater samples were taken from a fixed point at the North Coast of Egypt in The Mediterranean Sea, with total dissolved solids (TDS) of 42,200 mg/l.

2.2 Measuring instruments and error analysis

The set of the measuring instrumentations which used in this study are indicated in Table (2). All experiments were repeated several times and the obtained measured parameters had almost the same trend.

Several measurements have been done for "n" number of measured parameters, to calculate the errors in the results and the uncertainty in the measuring

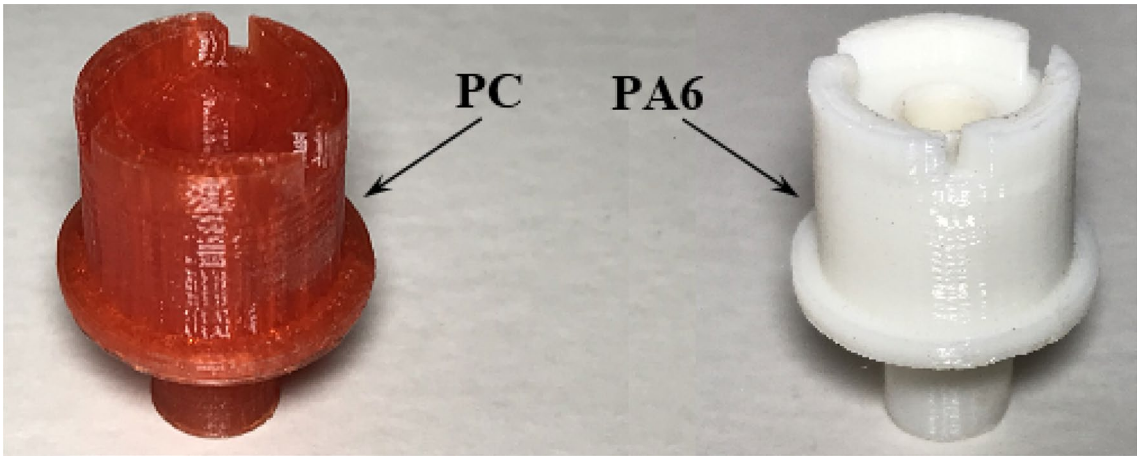

Fig. 4 Photograph of the proposed two vortex generators (PC and PA6) of the present study

instruments. Subsequently, the measured quantity mean was calculated as the following [23]:

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{N} X_i \tag{1}$$

While the standard deviation was calculated using the following equation [23]:

$$\sigma_X = \sqrt{\frac{1}{n-1}\sum_{i=1}^{N}(X_i - \overline{X})^2} \tag{2}$$

Finally, the error propagation was calculated using the following general equation [23]:

$$\delta R = \sqrt{\left(\frac{\partial R}{\partial X_1}\delta X_1\right)^2 + \left(\frac{\partial R}{\partial X_2}\delta X_2\right)^2 + \ldots. + \left(\frac{\partial R}{\partial X_n}\delta X_n\right)^2} \tag{3}$$

The error analysis' obtained values for all parameters are indicated in Table (3).

3 Results and discussion

Several experiments were carried out, to investigate the proposed RHVT/seawater desalination performance, with a new series arrangement under different vortex generator new materials of PC and PA6. Subsequently, elaborated analysis of the system temperature behavior, desalination rate and freshwater production were compared with previous work of Shmroukh et al. [13].

3.1 Effect of hot air mass fraction

The hot air mass fraction (HF) is defined as the ratio between RHVT outlet hot air quantity to its inlet total air quantity, choosing different HF values of 0.1, 0.5, 0.7 and 0.9 to examine the effect on desalinated water percentage for both tested vortex generators' materials in the modified arrangement as presented in Fig. (5). As shown in the mentioned figure, as HF increased as the percentage of desalinated water increased, due to the excess amount of hot air that passed to the evaporator, this increase tended until HF reached 0.5, then as HF increased more as the percentage of desalinated water decreased due to two main reasons, one is the increase in the evaporator pressure which tended to an increase in the required seawater evaporation temperature, while the second is the decrease in the cold air that passed to the condenser, moreover, the figure indicated that the optimum HF value of 0.5 was obtained at the maximum desalinated water percentage of both MPA6 and MPC arrangements. Therefore, this value of HF was fixed for all experiments.

Otherwise, a comparison of the temperature difference between both main hot and main cold airstreams of the evaporator and the condenser, respectively, for both modified arrangements with respect to HF is illustrated in Fig. (6). The highest value of the main hot and cold airstreams' temperature difference was obtained with MPC arrangement, which was reached approximately 48 °C, this may be attributed to its ability to increase the heat transfer between the hot and cold air streams.

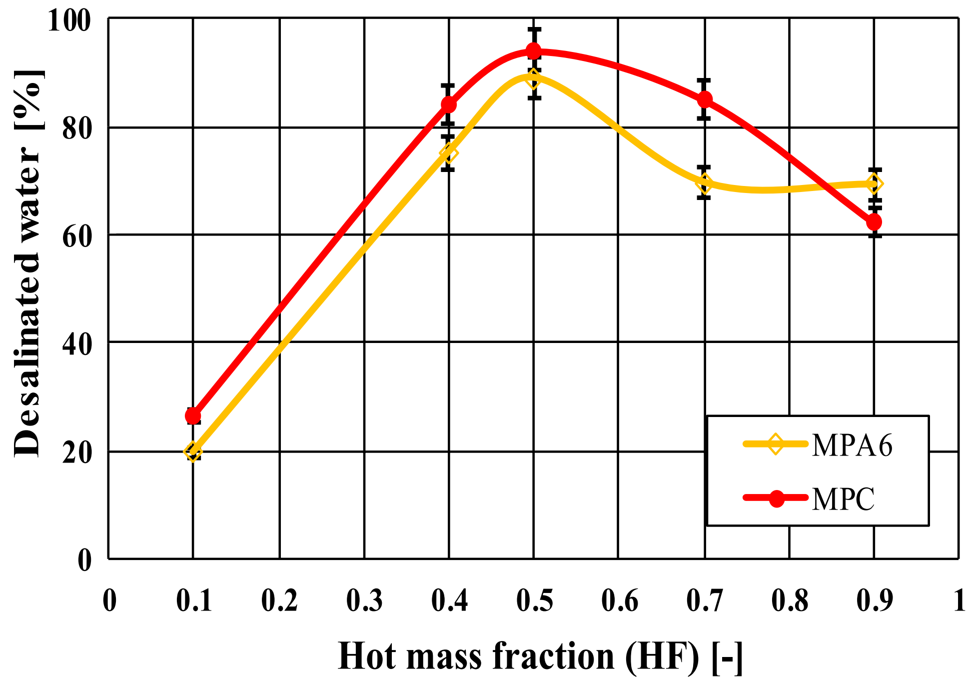

Fig. 5 Desalinated water percentage vs HF for the tested arrangements

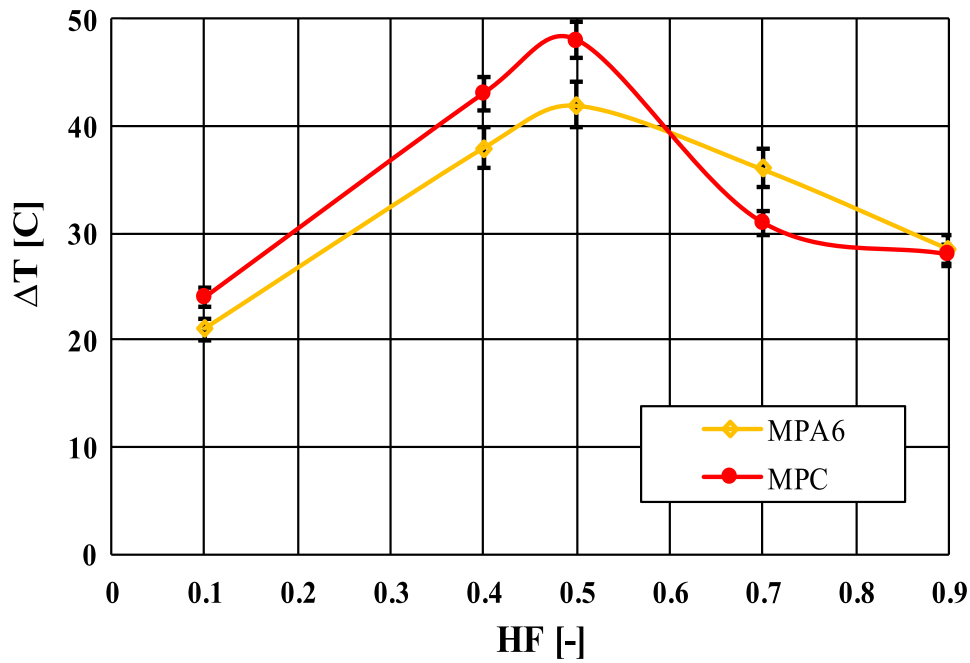

Fig. 6 The temperature difference between the main hot and cold airstreams vs HF for the tested arrangements

3.2 Effect of modifications on airstreams temperature

RHVT outlet airstreams temperature is a key factor to judge the effectiveness of the desalination system. Therefore, Fig. 7 indicated the trend of main hot air temperature for both modified arrangements, compared with that for the simple series hot vortex tube (SHVT) arrangement of Shmroukh et al. [13], with respect to total experimental time. It was clearly seen from this figure, that the temperature of hot airstream in the main hotline of the evaporator was increased with time until reached its maximum value after 180 min. Moreover, the present MPC and MPA6 arrangements had higher values for hot airstreams than that for SHVT of Shmroukh et al. [13]. On the other hand, the highest main hot airstream temperature of 88 °C was obtained by using the MPC arrangement. This means that the proposed generator

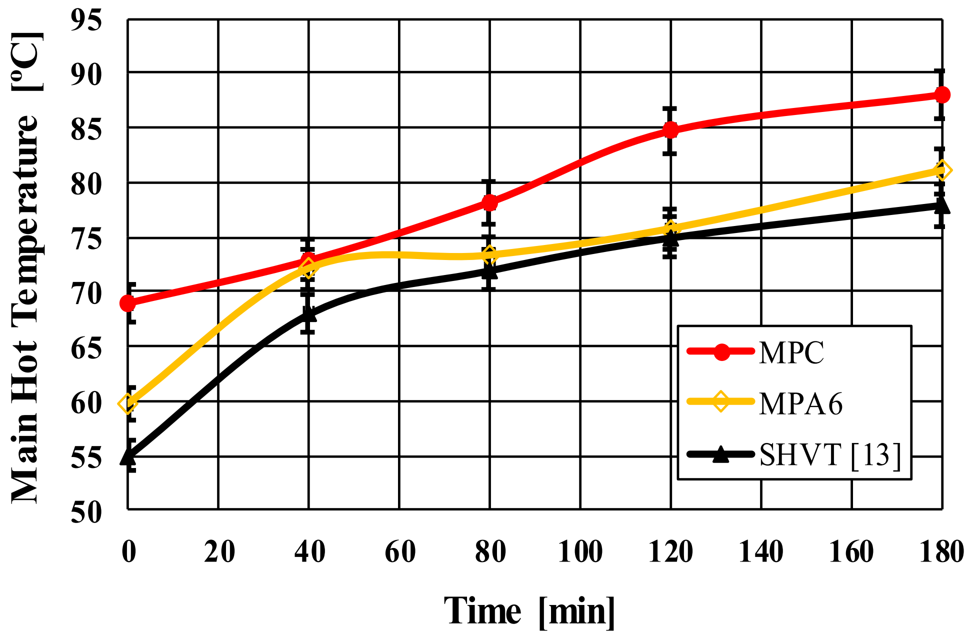

Fig. 7 Evaporator main airstream temperatures vs time

materials provide high energy separation effect in the vortex tube system since their density is low.

Furthermore, Fig. 8 illustrated the behavior of the main cold air temperature for both modified arrangements, compared with that for the simple SHVT arrangement of Shmroukh et al. [13], with respect to total experimental time. It was obviously seen from the figure, that the temperature of cold airstream in the main cold line of the condenser was decreased with time except for SHVT of [13], till it reached its minimum value after 180 min. Moreover, the present MPC and MPA6 arrangements had lower values for cold airstreams than that for SHVT of Shmroukh et al. [13]. On the other hand, the lowest main cold airstream temperature of 19 °C was obtained by using the MPC arrangement due to its high energy separation ability.

3.3 Effect of modifications on system productivity

Changing the materials of the vortex generators and using the new series RHVTs arrangement with seawater

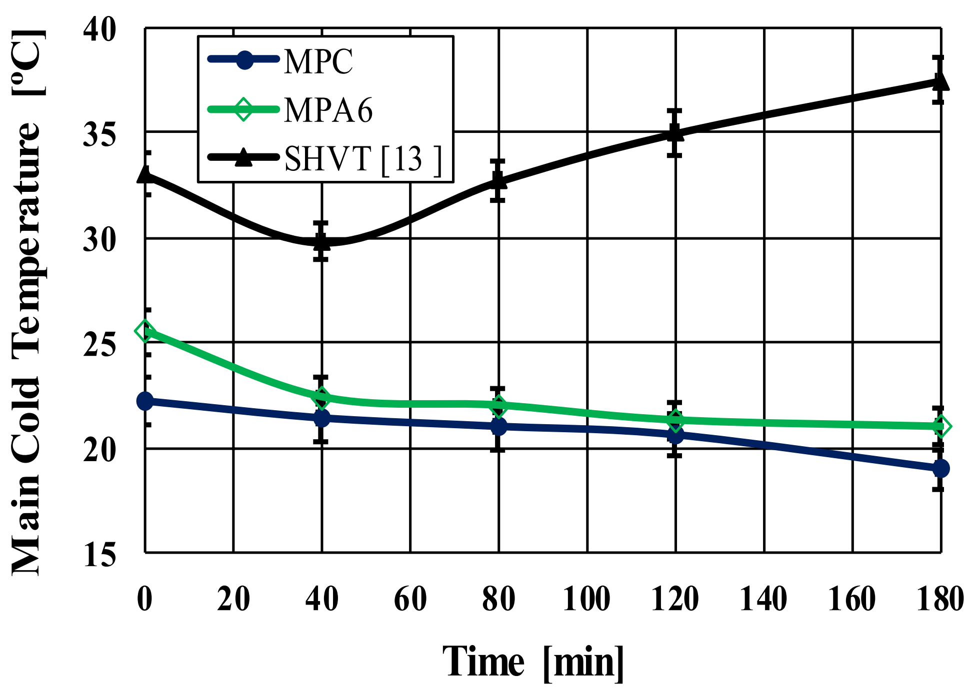

Fig. 8 Condenser main airstream temperatures vs time

preheater were affected the proposed system productivity as indicated in Fig. 9. According to this figure, freshwater production for both modified arrangements and SHVT of [13] was increased with time until reached its maximum value of 1880 ml with MPC system. While, a lower value was given with MPA6 of about 1780 ml, however the lowest value of freshwater production of 1580 ml was achieved by using the simple SHVT of [13], due to the decreased heat transfer between both hot and cold air streams inside the vortex tubes, which interns resulted in insufficient quantities of the evaporated water in the evaporator and the condensed water in the condenser.

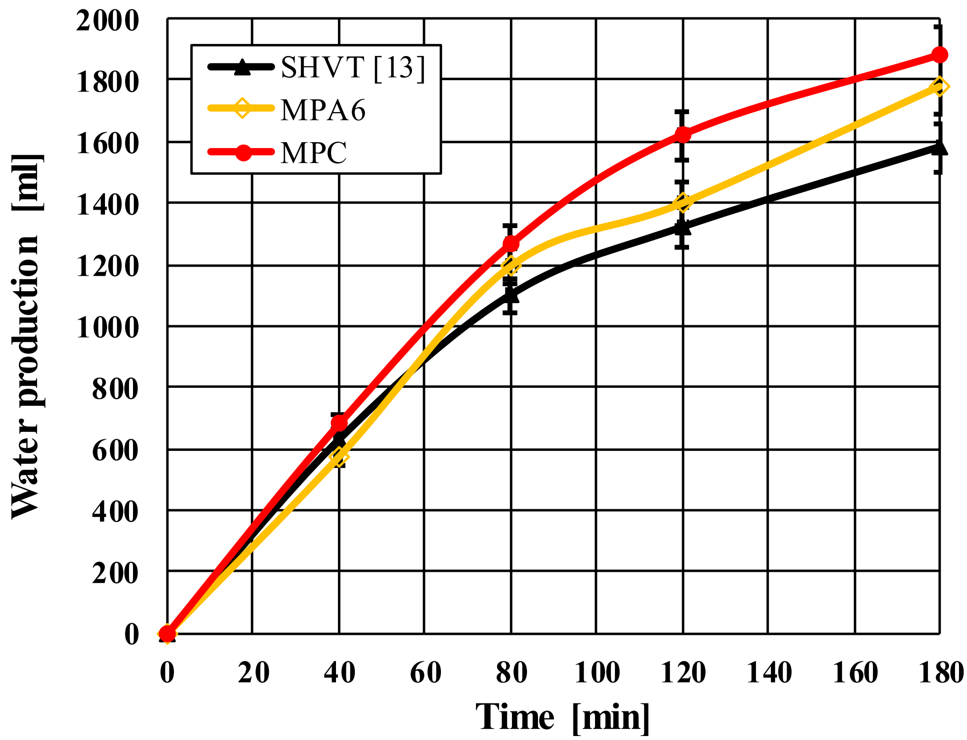

Fig. 9 Freshwater production vs time for the proposed system and SHVT of [13]

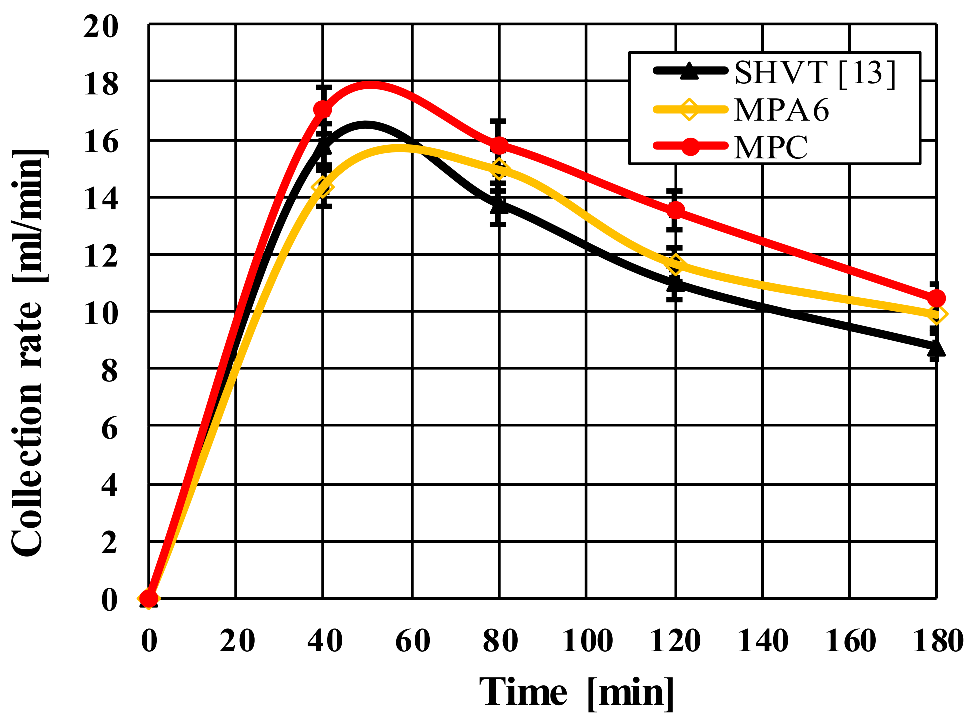

Fig. 10 Freshwater collection rate vs time for the proposed system and SHVT of [13]

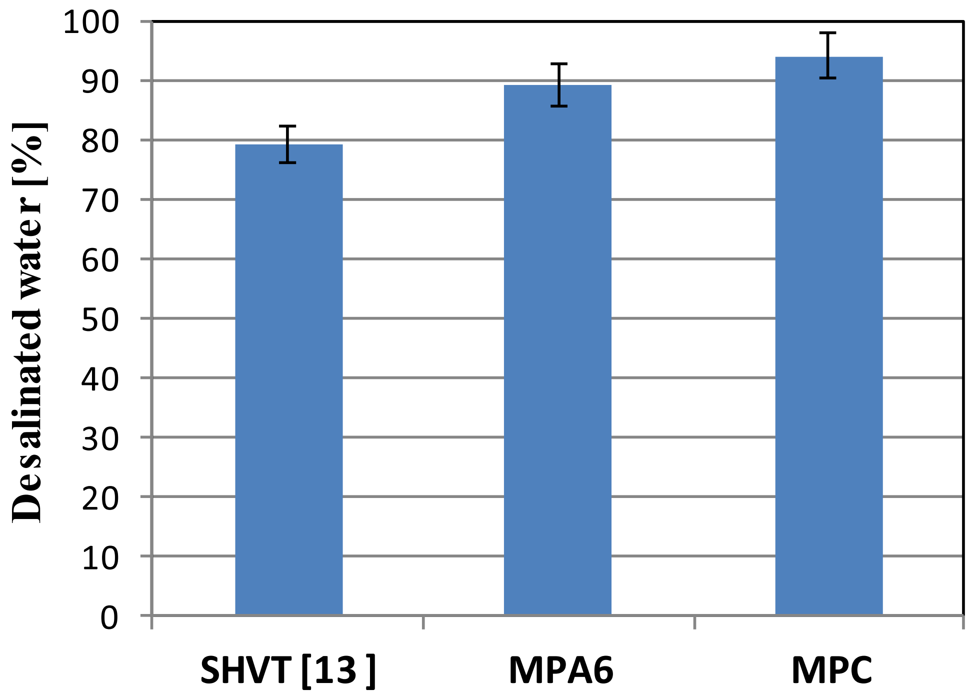

Fig. 11 Desalinated water percentage for the present study and the study of [13]

Table1 Thermophysical properties of the proposed vortex generator materials

Property	Polyamide-Nylon 6 (PA6)	Polycarbonate (PC)
Density (kg/m^3)	1130	1190
Thermal conductivity (W/m.K)	0.26	0.21
Specific heat (J/kg.K)	1700	1200

Table 2 Measuring instruments characteristics

Instrument	Characteristics
Water volume	Model: laboratory graded glass bottle [23] Capacity: 2000 ml with 5 ml minimum scale
Air flow rate sensor	Model: DVE Flow range: 0 to 300 l/min
Temperature sensor	Model: K- Type thermocouples [23] Temperature range: -50 °C to 150 °C Operating humidity: 5–95% RH
Pressure sensor	Model: MAN-RG26S Pressure range -1 to 15 bar Operating temperature: -20—85 °C
TDS meter	Model: Mi 806 [23] TDS range: 0 to 50,000 ppm Rated operating temperature range: 0 to 60° C

Comparison of the modified MPC and MPA6 systems collection rate during the experiment with respect to SHVT of [13] was represented in Fig. 10. According to the figure, the collection rate of the desalinated water was increased at the beginning 50 min of the experiment and then it was decreased, while the highest desalinated water collection rate was found in MPC system due to its high energy separation performance, while the simple SHVT of Shmroukh et al. [13] was given the lowest values of the collection rate. Moreover, the collected water quality analysis was presented in Table (4), as concluded from this table, the collected desalinated water had safe levels of PH, turbidity, conductivity, and TDS, which referred to be suitable for

Table 3 Values of the error in the measured parameters

Parameter	Error
Water volume flow rate	± 5 ml
Air volume flow rate	± 2%
Temperature	± 0.1%
Electrical energy Consumption	± 0.5%
Specific energy Consumption	± 0.85%

Table 4 Quality analysis of seawater and produced freshwater samples

Property	Seawater	Produced freshwater
PH	8.2	6.7
Conductivity (μS/cm)	870	83
Turbidity (NTU)	1.7	0.9
TDS (mg/l)	42,200	270

several human applications. Consequently, using the new modified MPC and MPA6 systems in the present study lead up to an increase in the RHVT/desalination system productivity and overall performance significantly.

The desalinated water percentage is defined as the ratio between the desalinated water quantity to the initial seawater quantity, desalinated water percentage comparison for the proposed modified arrangement and the simple arrangement of Shmroukh et al. [13] of MPC, MPA6, and SHVT, respectively, are indicated in Fig. 11. The presented data revealed that the MPC system of the present study was found to give the highest desalinated water percentage than that for MPA6 and SHVT of [13], with a value of up to 94% due to its ability to reduce unwanted radial heat flows from the peripheral to the axial vortex inside the wall, increase the radial temperature gradient near the swirl device, and thereby increase the efficiency of the vortex tube. While the lowest value of 79% was obtained by the simple arrangement of [13]. On the other side, Table (5) was emulated the geometrical and operational parameters of the present study's RHVTs and that of Shmroukh et al. [13].

3.4 Effect of modifications on system specific energy consumption

For energy consumption point of view, the consumed energy with respect to 1 L of desalinated water for the present modified systems were compared with that of Shmroukh et al. [13], Turek et al. [7] and Vlachogiannis et al. [24] and are illustrated in Table (6).

The consumed electrical energy for both MPC and MPA6 were the same due to the maintained operating conditions. Subsequently, MPC gave a lower value of 3.2 kWh/l for specific energy consumption than that of the MPA6 system, this was due to MPC higher desalinated water production. While the highest value of specific energy consumption was obtained from SHVT [13], due to its highest electrical energy consumption and lowest desalinated water production. otherwise, the lowest value of electrical energy consumption of approximately 0.159 kWh/l only was indicated by the proposed hybrid RO-electrodialysis system of Turek et al. [7], moreover, the proposed mechanical compression based desalination system of Vlachogiannis et al. [24] was obtained another lower electrical energy consumption value of 0.95 kWh/l than that of the present modified RHVT/desalination systems, therefore, it is highly recommended to enhance, improve and give more attention to RHVT/desalination technology for both used materials and vortex tubes arrangement point of view to become more efficient.

4 Conclusions

In this paper, a new series hot arrangement of two identical RHVTs in desalination system equipped with seawater pre-heater, and two different new materials of Polycarbonate

Table 5 Geometrical and operational parameters comparison with previous work for the used RHVTs

Parameter	Present work	Shmroukh et al. [13]
Vortex system	Two vortex tubes	Two vortex tubes
Inlet pressure, pi [bar]	4	4.5
Nozzle number, N [–]	3	3
Generator material	PC and PA6	Aluminum
Shape of hot tube	Straight	Straight
Working fluid	Air	Air
Compressor operation mode	10 min on / 5 min off	10 min on / 5 min off
Total experiment time, [min]	180	180

Table 6 Energy consumption data comparison of present work and other conventional systems

Configuration type	Experiment total time (min)	Compressor energy consumption (KWh)	Vacuum pump energy consumption (KWh)	Specific energy consumption with respect to freshwater produced(KWh/liter)
MPC	180	7.1	0.2	3.2
MPA6	180	7.1	0.2	3.8
SHVT [13]	180	9.4	0.2	7.8
Vlachogiannis et al. [24]	Not available	Not available	NO	0.95
Turek et al. [7]	Not available	Not available	NO	0.159

(PC), while the second was Polyamide-Nylon 6 (PA6) for the vortex generator were developed and examined, to eliminate the previous schemes draw backs and to enhance the desalination system performance, by decreasing the compressor input energy using lower pressure air streams, enhancing the energy separation of the air streams inside the vortex tubes and by utilizing the excess heat in the relatively hot air stream in seawater preheating, such air stream exited from the second vortex tube was treated as disposal and lost without use in the previous schemes. Subsequently some significant outcomes can be drawn based on the present experimental work. The modified arrangement with PC vortex generator (MPC) provided the best thermal performance because the major hot air temperature point of 88 ºC and the minor cold air temperature point of 19 ºC were achieved by such MPC arrangement. Furthermore, the desalinated water quantity reached approximately 94% of the initial seawater quantity for the MPC arrangement due to the ability of PC based vortex generator of low thermal conductivity to reduce unwanted radial heat flows from the peripheral to the axial vortex inside the wall and increase the radial temperature gradient near the swirl device, and thereby enhance the vortex tube performance, otherwise, the desalinated water quantity was about 89% when using the modified arrangement with PA6 vortex generator (MPA6). Therefore, using both Polycarbonate vortex generator and seawater preheater is recommended for performance improvement of the RHVT/seawater desalination system. Moreover, the produced water could be used in several human-based applications, in result of its quality parameters which reached safe level values. On the other hand, it is recommended for future work to study more new materials for the vortex generator with ultra-high-quality manufacturing and surface roughness to enhance the vortex generator performance. Moreover, the electrical energy consumed by such RHVT/seawater desalination system is still high compared with other conventional desalination systems, so it is recommended also to use more efficient low power consumption compressor. Therefore, RHVT based seawater desalination technology needs strengthen focus for more enhancement.

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Compliance with ethical standrads

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest. Moreover, all authors declare that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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