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Productivity Augmentation of New Seawater Desalination Plants Integrating Absorption Desalination and Humidification/Dehumidification Plants Through Thermal Recovery

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A B S T R A C T

Solving water deficiency, energy crisis, and environmental concerns are typical practices in energy engineering practice nowadays. This work presents a new and effective integration between absorption (ABDP) and humidification-dehumidification (HDH) cycles using thermal recovery technique is theoretically investigated. Two scenarios are used to recover and exchange thermal energy between the rejected condensate heat from the ABDP condenser and the incoming saline feed water to the HDH humidifier and between the ABDP evaporator and the HDH dehumidifier. Performance of the proposed integrated ABDP-HRH are assessed and compared with the standard ABDP and HDH desalination plants. The results obtained showed that the presented thermal recovery scenarios have an effective enhancement in potable water production and GOR. An increasing generator temperature from 60 to 120°C elevates the productivity of the proposed integrated ABDP-HRH from 0.466 to 2.72 m3day-1 and the GOR from 2.12 to 2.38. The enhancement in the productivity of the proposed integrated ABDP-HRH was between 97.38 to 99.15 % while for the GOR was between 127.08 to 129.11% compared with those of the ABDP.

1. Introduction

T Fresh water and energy are intricately linked factors that have a big influence on our daily lives and the evolution of society [1]. Freshwater shortage is a pressing and sensitive issue globally that must be considered and addressed due to the escalating worries regarding its effects on surrounding and human and animal presence now and in the future [2, 3]. The most viable and workable solution to this issue is to use desalination cycles to help meet the growing demand for drinking water [4]. In 2025, a large proportion of the world's population, about 60%, is expected to suffer from lack of access to safe drinking water. It is also expected that about 80-90% of diseases will be caused using water that is not suitable for human use, and about 30% of deaths [5]. Therefore, solving the problem of water scarcity has become urgent and necessary, whether by developing current technologies to increase productivity or by introducing new technologies such as hybrid technologies to save energy and increase productivity [6].

Nowadays, desalination plants such as multiple flash distillation (MSF) and multiple effect distillation (MED) are widely used and are considered the first choice for water desalination, especially in countries suffering from electricity shortages [7]. However, these plants are energy-intensive and expensive. On average, they require around 190 to 282 MJ/m^3 of thermal energy to convert water brine into vapor and between 2.5 and 12 kWh/m^3 of electrical energy to operate other accessories such as pumps and controls [8,9].

Recently, sorption desalination plants have been considered as viable alternative to address the issue of water shortage and high energy consumption [10,11]. They are inexpensive, run on low-cost heat including solar or waste heat, and do not pollute the environment compared to conventional technologies [12,13]. The humidification and dehumidification (HDH) cycle can be considered as an advanced version of the solar distillation devices [14]. The standard HDH system contains a heater, humidifier and dehumidifier. The heat source can be also low-grade heat such as solar or waste heat [15]. The feed water is pumped into the dehumidifier, then heated in the heater and finally flows into the humidifier. At the same time, ambient air is blown to humidify inside the humidifier with salt water and then condensed inside the dehumidifier with cold salt water to produce potable water [16]. However, both sorption desalination and HDH plants have the disadvantage of low daily productivity, which needs more research and development to improve their performance [17]. Hybrid desalination systems that combine two or more technologies together, whether similar or different, can greatly increase daily productivity as well as overall system efficiency, thus reducing production cost and preventing environmental pollution [18, 19].

Some studies on hybrid desalination systems that combine HDH, or sorption desalination cycles have been conducted recently to increase daily productivity, reduce consumption, and improve performance [20]. The absorption cycle used for desalination of salt water was initially introduced by Harby et al. [21]. In this work, a theoretical simulation was conducted to integrate both absorption desalination (ABDP) and reverse osmosis plants (ROP) to treat the output of RO and enhance productivity. The rejected output from the ROP was fed into the evaporator of the ABDP. They concluded that integration of ABDP and ROP enhances the recovery rate by 73.88%. In addition, the quality of produced water rises by 59.32%. The consumption of energy was minimized by around 49.3%. Alelyani et al. [22] also presented a theoretical study to integrate both absorption cooling cycle used NH_3/H_2O as cooling medium and MED plant. The cooling and desalination cycles were combined in a cascade technique. They summarized that the exergy energy was minimized by 55.2% compared to that of the MED plant. Alarcon and Garca [23] conducted similar research on the integration of an absorption cooling cycle and MED plant. They summarized that the efficiency and production of the integrated plants enhanced significantly. Harby et. al [24] provided a theoretical work on the integration of adsorption desalination (ADDP) and HDH desalination cycles with external heat recovery process. Four external recovery techniques were introduced and discussed, and the outcomes were compared. They summarized that the higher yield was between 1.58 and 2.96 $m^3.day^{-1}$ with a GOR of 1.38 and 1.76 at 12 °C. The produced freshwater and GOR enhanced by 618.6-225 % and 222.6 to 99.2 %, respectively.

The HDH desalination plants have been also investigated by different researchers to enhance the daily yield and efficiency [25]. To enhance the daily output, Ehab et al. [26] provided a theoretical simulation on the integration of HDH and ADDP. Two scenarios of integration with heat recovery process were introduced and discussed between HDH and ADDP. The summarized that the daily water output and GOR enhanced by 180.5% and 23.5%, respectively. Dehghani et al. [27] provided a theoretical simulation on the combination of HDH cycle and heat pump cycle. The integrated cycle generated cooling and heating effects. They summarized that the output yield is reduced, and the cost ranged between $13.6 and $18.7 per cubic meter. Zhao et al. [28] also introduced practical work on the daily yield of the integration of a 4-stage HDH with the direct-contact scenario. They investigated the impact of changing hot water temperatures on system performance. The higher GOR was around 1.42 with water cost of $3.86/$m^3$.

In this research, the productivity and energy utilization of an innovative integrated absorption (ABDP) and HDH desalination plants has been enhanced by using a new heat recovery technique. The system is powered by low grade heat temperatures. To enhance the energy utilization and system efficiency of the proposed integrated plant (ABDP-HRH), the feed saline water of the HDH humidifier is preheated heat of condensation rejected from the ABDP condenser through a thermal recovery technique. This can reduce condenser temperature, increase evaporation process, and enhance ABDP productivity and performance. In addition, preheating the seawater of the HDH humidifier enhances the evaporation process inside humidifier, raises HDH productivity, and elevates the utilization of the used heat source. Another thermal recovery technique is applied between the ABDP evaporator and dehumidifier. The heat released through the dehumidification process of the HDH dehumidifier is absorbed by the cooling process of the ABDP evaporator. This enhances the rate of condensation through the HDH dehumidifier, enhances the performance of the ABDP, and HDH productivity. Higher temperatures in the ABDP evaporator cause the feed saline water to evaporate more quickly, which in turn raises the amount of potable water outlet from the ABDP. The performance and productivity of the proposed integrated plant (ABDP-HRH) are analyzed and compared with the standard ABDP and HDH desalination plants.

2. System description and operation

The main aim of this work is to raise the productivity and energy utilization of an innovative integrated absorption desalination (ABDP) and HDH desalination plants using a new heat recovery technique. The performance and yield of the suggested are provided and compared with the standard ABDP and HDH desalination plants. Through the proposed integrated ABDP/HDH plant, the feed saline water flows to the humidifier are preheated by passing it firstly into the condenser of the ABDP through a thermal recovery technique. In which the feed saline water is preheated by the heat rejection from the condensation process of ABDP condenser. This can reduce the condenser temperature of the ABDP, elevate evaporation rate of the ABDP plant, and thus enhance the productivity and performance of ABDP. In addition, preheating the seawater of the HDH humidifier enhances the evaporation process inside the HDH humidifier, raises the potable water outlet from the HDH, and elevates the utilization of the used heat source. Another thermal recovery technique is used between the evaporating element of the ABDP and dehumidifier of the HDH cycle. The heat rejected during the dehumidification process of HDH cycle is absorbed by the cooling action of the ABDP evaporator. This has the potential to increase the rate of condensation through the HDH cycle and thus enhance the potable water outlet. Furthermore, higher temperatures in the evaporator of the ABDP cause the feed saline water to evaporate more quickly, which in turn raises the amount of potable water outlet from the ABDP.

When the proposed integrated ABDP-HRH plant is in operation, the feed saline is fed to the ABDP evaporator through a set of dispensers. The saline water contacts the cold coils of the evaporator, it evaporates at the evaporator temperature. In addition, the chilled water is exchanged with that of the HDH humidifier, as shown in Fig. 2. The operating principle of ABDP is provided in the previous study [21]. Then, the evaporated water is absorbed by the strong solution in the absorber at point 10. Then the mixture of LiBr and H2O is pumped by a water pump into the generation unit through a heat exchanger. The generator is driven by a low-grade heat source from solar energy source. In the generator, the temperature of the solution pumped from the absorber is raised, causing evaporation of the water content and passing under pressure to the condenser via the mist removal unit. As a result of the high temperature in the generator, water vapor separates from LiBr solution due to the lower boiling point of water compared to LiBr. The mist removal unit installed at the generator outlet prevents lithium bromide (LiBr) droplets from entering the condenser [21, 29]. On the other side, the strong LiBr flows back to the absorber passing into the expansion valve to lower its temperature and absorb more water vapor from the evaporating element. When the water vapor produced by the

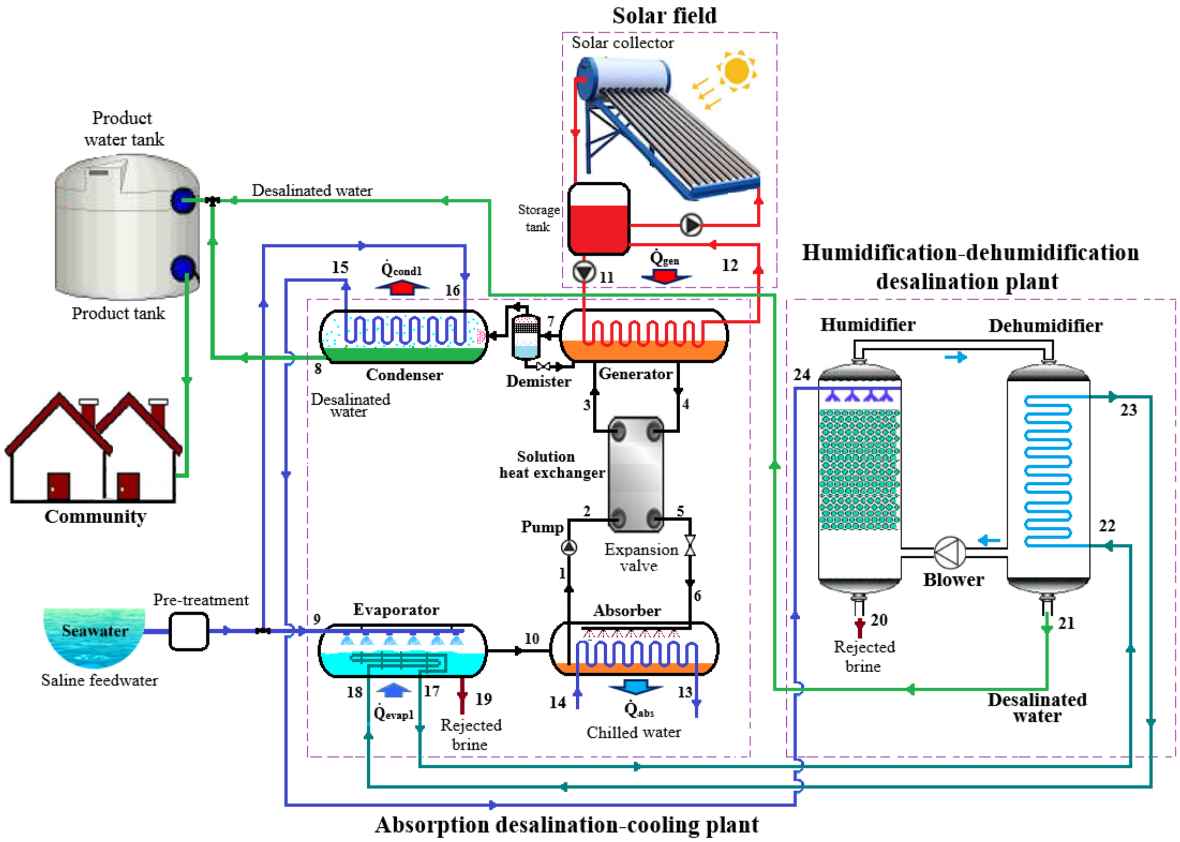

Figure 1: Schematic of proposed ABDCP and HDH desalination plants with thermal recovery between condenser/humidifier and evaporator/dehumidifier

generator enters the condenser, it condenses on the feed slain water pipes that feed the HDH humidifier (as shown in Fig. 3) and produces the first fresh water of the ABDP-HRH plant. This can reduce the condenser temperature of the ABDP, elevate evaporation process of the ABDP plant, and thus enhance the productivity and performance of ABDP. In addition, preheating the seawater of the HDH humidifier enhances the evaporation process inside the HDH humidifier, raises the potable water outlet from the HDH, and elevates the utilization of the used heat source. Another. The preheated feed saline water is then fed to the HDH humidifier through a set of dispensers over the blown air in the humidifier. The compressed air becomes more humid as it carries water vapor in the humidifier and is then sent to the HDH dehumidifier. As the air passes through the cooling coils connected to the ABDP evaporator it condenses and produces the second fresh water ABDP-HRH plant.

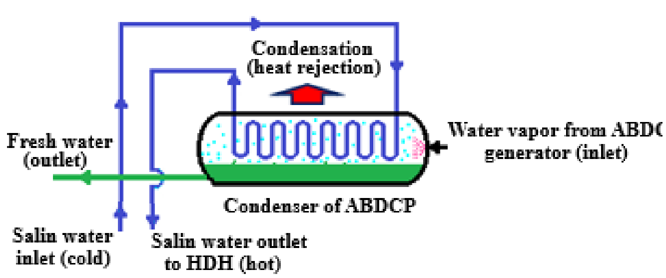

Figure 2: Schematic diagram showing the inputs and outputs during the heat recovery process in the ABDCP condenser between ABDP and HDH plants

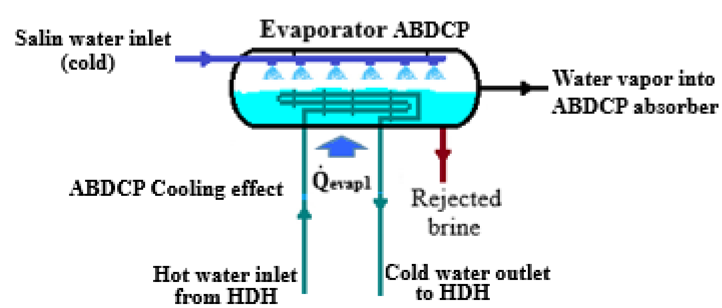

Figure 3: Schematic diagram showing the inputs and outputs during the heat recovery process in the ABDCP evaporator between ABDP and HDH plants

3. Mathematical analysis

3.1. Model assumptions

The assumptions were considered as follows:

- All elements at constant pressure except expansion element.

- Heat loss is negligible.

- Kinetic and potential energy are not considered.

- Saturation conditions at the outlet of the condensing, evaporating, and generating elements.

- Electric energy for operating pumps and blower is neglected [30,31].

- Air is 100% saturated at the outlets of the dehumidifier and humidifier.

- Feed water at 25°C.

3.2. Modeling ABDP

Generator

Through the generator, the temperature of LiBr-H_2O solution is elevated by the connected heat source $\dot{Q}_g$ and the water vapor flow to the condenser as potable water.

$$\dot{Q}_g = \dot{m}_4 h_4 + \dot{m}_7 h_7 - \dot{m}_3 h_3 \quad (1)$$

$$\dot{Q}_g = UA_{gen} \Delta T_{Lm,gen} \quad (2)$$

$$\dot{Q}_{gen} = \dot{m}_{11}(h_{11} - h_{12}) = \dot{m}_{11} cp (T_{11} - T_{12}) \quad (3)$$

$$\dot{m}_3 = \dot{m}_4 + \dot{m}_7 \quad (4)$$

$$\dot{m}_3 x_3 = \dot{m}_4 x_4 \quad (5)$$

Condenser

During the condensation process, the water vapor coming from the generator (point 7) is cooled by exchanging heat with saline feed water, then the vapor is condensed and used as potable water (point 8) from the ABDP.

$$\dot{Q}_c = \dot{Q}_e = \dot{m}_7 h_7 - \dot{m}_8 h_8 \quad (6)$$

$$\dot{Q}_c = \dot{m}_{15}(h_{16} - h_{15}) \quad (7)$$

$$\dot{Q}_c = UA_c \Delta T_{Lm,c} \quad (8)$$

$$\dot{m}_8 = \dot{m}_{P,ABDP} \quad (9)$$

$$\dot{m}_7 = \dot{m}_8 \quad (10)$$

Evaporator

During the evaporator, the feed saline water of the ABDP is fed (point 9) and the brine outlet (point 19) $\dot{m}_{19} = \dot{m}_{b,ABDP}$. The chilled water from the evaporator ($\dot{Q}_e$) is used to cool down the moist air inside the dehumidifier and the moisture condensed and produced another fresh water from the HDH.

$$\dot{Q}_e = \dot{m}_{10} h_{10} + \dot{m}_{19} h_{19} - \dot{m}_9 h_9 \quad (11)$$

$$\dot{Q}_e = \dot{m}_{17}(h_{18} - h_{17}) \quad (12)$$

$$\dot{Q}_e = UA_e \Delta T_{Lm,e} \quad (13)$$

$$\dot{m}_9 = \dot{m}_{s,ABDP} = \dot{m}_{10} + \dot{m}_{19} \quad (14)$$

Absorber

During the absorption element, the vapor ($\dot{m}_{10} h_{10}$) is absorbed by the strong LiBr.

$$\dot{Q}_a = \dot{m}_6 h_6 + \dot{m}_{10} h_{10} - \dot{m}_1 h_1 \quad (15)$$

$$\dot{Q}_a = \dot{m}_{13}(h_{14} - h_{13}) \quad (16)$$

$$\dot{Q}_a = UA_a \Delta T_{Lm,a} \quad (17)$$

$$\dot{m}_1 = \dot{m}_6 + \dot{m}_{10} \quad (18)$$

$$\dot{m}_1 x_1 = \dot{m}_6 x_6 + \dot{m}_{10} x_{10} \quad (19)$$

Heat exchanger

$$\dot{Q}_{he,cold} = \dot{m}_1 (h_3 - h_2) \quad (20)$$

$$\dot{Q}_{he,hot} = \dot{m}_4 (h_4 - h_5) \quad (21)$$

$$\varepsilon_{SHX} = (T_4 - T_5)/(T_4 - T_2) \quad (22)$$

Pump

$$\dot{W}_{pump,ABDC} = \frac{\dot{m}_1 \upsilon_1 (P_{high} - P_{low})}{\eta_{pump}} = h_2 - h_1 \quad (23)$$

Table 1 presents the design factors of the tested ABDP as given by [32].

Table 1: Design factors of the tested ABDP [32]

Input parameters	**Symbols**	**Unit**	**value**
Heat exchanger effectiveness	ε_{SHX}	-	**0.61**
Pump mass flow rate	$\dot{m}_1$	**kgs^{-1}**	**0.55**
Overall heat transfer coefficient for absorber	UA_{abs}	**kWk^{-1}**	**2.1**
Overall heat transfer for condenser	UA_{cond}	**kWk^{-1}**	**1.81**
Overall heat transfer coefficient for generator	UA_{gen}	**kWk^{-1}**	**1.61**
Overall heat transfer coefficient for evaporator	UA_{evap}	**kWk^{-1}**	**0.61**

A mist eliminator is applied at the generator outlet as displayed in Fig. 1 to prevent the lithium bromide droplets from flowing into the condenser element with the water vapor where the water is filtered and returned to the generator element. The pressure drop (loss) equation for the mist eliminator used can be given as follows [33]:

$$\Delta p_{demister} = 9.584 \times 10^4 (\rho_d)^{1.598} (V)^{0.7107} (L_d)^{1.389} \quad (24)$$

where ρ_d is the density of the used mist eliminator and equal around 320 kg/m3, L_d is the mist eliminator thickness and equal to 0.11 m, and V is the velocity of vapor in the mist eliminator.

3.3. Modeling HDH

The HDH desalination consists of dehumidifier, blower, and humidifier. The feed water is preheated in the ABDP condenser and then enters the humidifier at point 24. The productivity of the HDH was produced in the dehumidifier at point 21. The heat and energy balance correlations across HDH components can be given as follows:

The conservation of mass and energy of the humidifier is as follows:

$$\dot{m}_{w_H} = \dot{m}_{saline} - \dot{m}_{brine} = \dot{m}_{air}(\omega_{air,o} - \omega_{air,i}) \quad (25)$$

$$\dot{m}_{air}(h_{air,o} - h_{air,i}) = \dot{m}_{brine}\, h_{brine} - \dot{m}_{sw} h_{sw,i} \quad (26)$$

The conservation of mass and energy of dehumidifier as follows:

$$\dot{m}_{p,HDH} = \dot{m}_{air}(\omega_{i,air} - \omega_{o,air}) \quad (27)$$

$$\dot{m}_{saline}(h_{w,i} - h_{air,i}) = \dot{m}_a(h_{air,o} - h_{air,i}) - \dot{m}_{w_{HDH}}\, h_{dw} \quad (28)$$

3.4. System performance

The total productivity from the proposed integrated plants ABDP-HRH as the follow:

$$\dot{m}_p = \dot{m}_{P,ABDP} + \dot{m}_{p,HDH} \quad (29)$$

The total distillate productivity for the proposed integrated plants ABDP-HRH in kJkg-1 as the follow:

$$\dot{Q}_p = \dot{Q}_{P,ABDP} + \dot{Q}_{P,HDH} = \dot{m}_{P,ABDP} h_{fg} + \dot{m}_{P,HDH}\, h_{fg} \quad (30)$$

The performance of the suggested plants ABDP-HRH can be given also by the gained output ratio (GOR) and the ratio of water-to-air mass flowrate (MR):

$$GOR = \frac{\dot{m}_{P,ABDP} h_{fg}}{\dot{Q}_g} + \frac{\dot{m}_{P,HDH} h_{fg}}{\dot{Q}_g} = GOR_{ABDP} + GOR_{HDH} \quad (31)$$

$$MR = \frac{\dot{m}_{saline}}{\dot{m}_{air}} \quad (32)$$

where $\dot{m}_{air}$ is the air in kg entering the humidifier and $\dot{m}_{sw}$ is the saline feed water entering the humidifier.

The enhancement (%) in productivity and GOR for proposed integrated plants ABDP-HRH compared with that of the ABDP as follows:

$$WP_{enhancement}(\%) = \frac{\dot{m}_p - \dot{m}_{p,ABDP}}{\dot{m}_{p,ABDP}} \times 100 \quad (33)$$

$$GOR_{improvement,plant}(\%) = \frac{GOR - GOR_{ABDP}}{GOR_{ABDP}} \times 100 \quad (34)$$

The developed models described above from Equations 1 to 34 are implemented and simulated by Engineering Equation Solver (EES).

4. Model validation

Since this is the first time that the ABDP and HDH desalination plants are connected by thermal recovery scenarios as mentioned above and there is no practical or theoretical study for comparison, the validation of the mathematical model will be for each plant separately. Firstly, the outcomes from the developed ABDP model are compared with the outcomes by Balghouthi et. al [50]. Table 2 displays a comparison between the outcomes from the actual study and that of previous investigation. The parameters include cooling capacity, performance (COP), and heat of condensation and absorption, and regeneration heat. As shown, the deviation between the actual data and those reported in the literature is below 0.72%. These low deviations show the validity of the ABDC model.

Figure 4 presents a comparison of GOR achieved by the proposed integrated ABDP-HRH and that obtained by Sharqawy et. al [30] at different values of MR. As demonstrated, the deviation between the data obtained from the actual study and those given in the literature is below 3.1%, As demonstrated, there is less than a 3.1% discrepancy between the experimental data given by Sharqawy et. al [30] and outcomes of the developed HDH model. These low deviations show the validity of the HDH model.

Table 2: Validation of ABDP model with experimental data obtained by Balghouthi et. al [32]

Parameter	Value	ABDP model	Error [%]
$\dot{Q}_a$ [kW]	14.69	14.71	0.32
$\dot{Q}_c$ [kW]	11.89	11.83	0.42
$\dot{Q}_g$ [kW]	15.27	15.31	0.32
$\dot{Q}_e$ [kW]	11.33	11.18	0.53
COP [-]	0.74	0.72	0.73
$\dot{m}_{P,ABDP}$ [m^{3}day^{-1}]	-	0.50	-

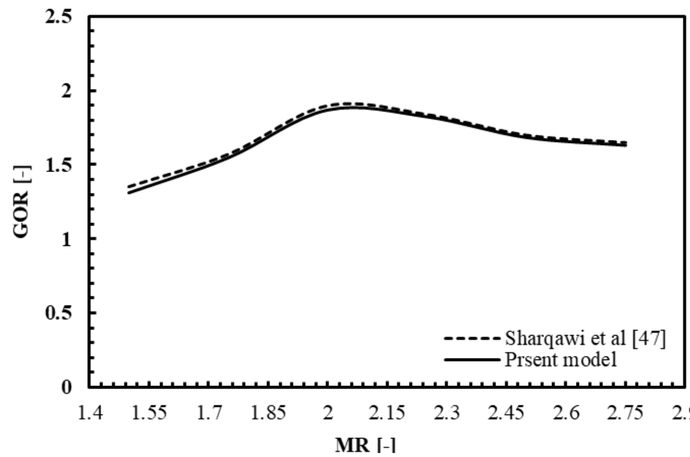

Figure 4: Comparison of GOR achieved by the proposed integrated ABDP-HRH and that obtained from the open literature at different values of MR

5. Results and Discussion

This section assesses the performance of the integrated plants (ABDP-HRH) in terms of productivity ($\dot{m}p$) and GOR. The outcomes from the integrated plants (ABDP-HRH) were also compared with that of ABDP, HRH, and relevant studies. The performance was evaluated at different heat source temperatures from 60 to 120 ºC.

5.1. Outlet temperature

As mentioned above, the feed saline water into the humidifier is preheated by passing it firstly into the ABDP condenser. In this case, the feed saline water is preheated before passing into the HDH humidifier by absorbing the heat emitted from its condensation process of the ABDP condenser. Preheating the feed water entering the HDH humidifier enhances the evaporation process inside the humidifier and thus increases the production rate of the HDH desalination plant. In addition, the absorption of condensation heat lowers the condenser temperature and thus improves the evaporation rate and ABDP production. This in turn increases the overall performance of the proposed integrated

ABDP-HRH plant. Figure 5 presents the saline water temperature outlet from ABDP condenser and entering HDH humidifier and MR (given by Eq. 32) vs. regeneration temperatures. As demonstrated, the saline water temperature (Tcond, out) that enters the HDH humidifier raises linearly with the regeneration temperatures. This is because as the heat source temperature inside the regenerator increases, more water vapor (potable water) evaporates from the solution (H2O-LiBr) inside the regenerator and flows at a higher speed and quantity to the condenser. Thus, increasing the heat rejection from the condenser into the saline water temperature going to the HDH humidifier. Elevating regeneration temperatures from 60 to 120 oC linearly raises the feed saline water temperature to HDH humidifier from 1.139 to 1.77. In addition, the MR that presents the ratio between the mass flow rates of saline water and air flow are also raises with the regeneration temperatures. Elevating hot water temperatures from 60 to 120 oC linearly raises the MR from 32.94 to 57.54 oC.

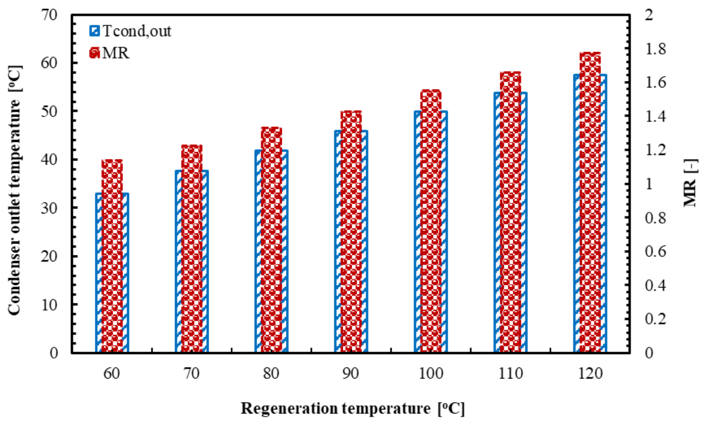

Figure 5: Salin water temperature outlet from ABDP condenser and entering HDH humidifier and MR vs. regeneration temperatures.

5.2. Productivity and performance

Figure 6 displays a comparison between the productivity of the proposed integrated plant (ABDP-HRH) and that of standard ABDP and HRH at different generator temperatures. Increasing regeneration temperatures increases the productivity of the proposed integrated plant (ABDP-HRH), standard ABDP, and standard HRH linearly. This is because increasing regeneration temperature increases the evaporation of water into the condenser and thus productivity. In addition, the absorption and evaporation rate in the absorber and evaporator respectively increases with the regeneration temperature. In addition, the productivity generated from the proposed integrated plant (ABDP-HRH) is higher than that of the HRH and ABDP. The higher productivity results from ABDP-HRH followed by HRH, and finally with ABDP. Increasing the generator temperature from 60 to 120°C enhances the productivity of the proposed integrated ABDP-HRH from 0.466 to 2.72 m3day-1. While it increases the HRH and ABDP throughput from 0.263 to 1.52 m3day-1and from 0.234 to 1.377 m3day-1respectively. This is due to the heat recovery technique applied between the ABDP evaporator and the HRH dehumidifier and the preheating of the saline water by the heat removed from the condensation process as mentioned before. This has greatly improved the productivity of ABDP and HDH cycles.

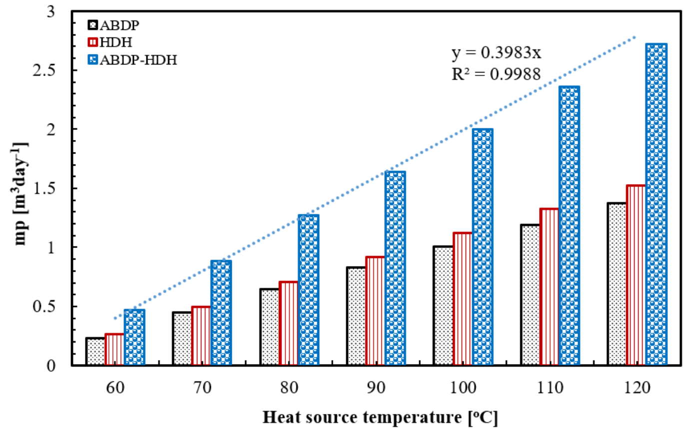

Figure 6: Comparison of the proposed integrated plant (ABDP-HRH) productivity with the standard ABDP and HRH productivity at different generator temperatures

Figure 7 presents a comparison of GOR of the proposed integrated plant (ABDP-HRH) with that of the standard ABDP and HRH at different generator temperatures (60 - 120 oC). The higher GOR results from ABDP-HRH followed by HRH, and finally with ABDP. Increasing regeneration temperatures increases the GOR of the proposed integrated plant (ABDP-HRH), standard ABDP, and standard HRH linearly. Increasing the generator temperature from 60 to 120°C increases the GOR of the proposed integrated ABDP-HRH from 2.12 to 2.38. While it increases the HRH and ABDP throughput from 1.195 to 1.333 and from 0.926 to 1.049, respectively. This is because the proposed integrated system enhances the evaporation rate and energy utilization through the used thermal recovery techniques and preheating the saline water before the HDH dehumidifier.

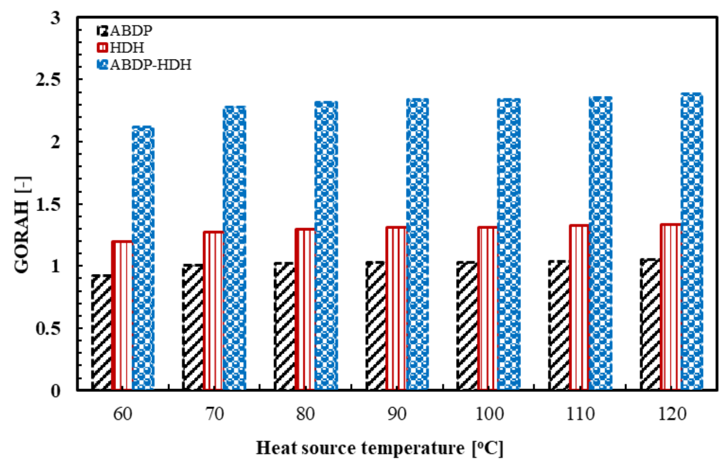

Figure 7: Comparison of GOR of the proposed integrated plant (ABDP-HRH) with that of the standard ABDP and HRH at different generator temperatures

5.3. Performance enhancement

Figure 8 displays the improvement in yield (%) and GOR (%) of the integrated ABDP-HRH compared with ABDP at different regenerator temperatures ranging from 60 to 120 oC. As illustrated, the enhancement in productivity mpenhancement (%) of the proposed integrated ABDP-HRH ranging from 99.18 at 60 oC to 97.38 at 120 oC. Raising regeneration temperature from 60 to 120 oC decreases the productivity enhancement (%) from 99.15 to 97.38% compared with the ABDP, this may be due to heat losses. The higher enhancement in productivity (%) is achieved at 60 oC. On the other hand, the higher GOR enhancement (%) is also achieved at lower regeneration temperatures. Increasing regeneration temperature from 60 to 120 oC decreases the GOR enhancement (%) from 129.11 to 127.08% compared with the ABDP, this may be due to heat losses.

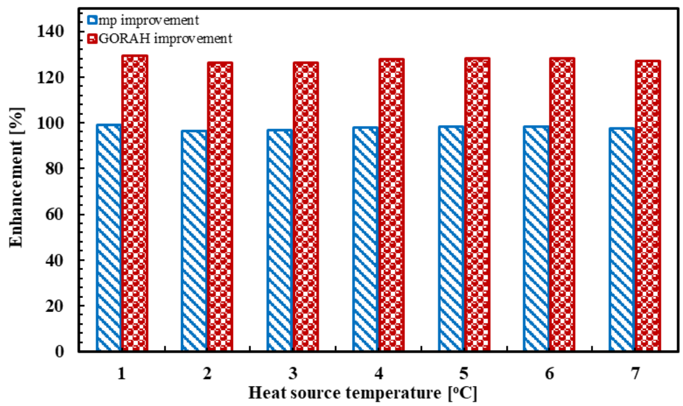

Figure 8: The enhancement in productivity (%) and GOR (%) of the proposed integrated ABDP-HRH compared with ABDP at different regenerator temperatures

6. Conclusions

In this work, an attempt to integrate absorption desalination (ABDP) and HDH desalination plants to enhance the yield, thermal energy utilization, and overall plant performance by utilizing thermal recovery techniques is theoretically investigated. Thermal recovery techniques are used to exchange heat energy between the incoming saline feed water to the HDH humidifier and the rejected condensation heat from the ABDP condenser and between the ABDP evaporator and the HDH dehumidifier. The performance and productivity of the proposed integrated ABDP-HRH are analyzed and compared with the standard ABDP and HDH desalination plants. The outcomes can be summarized as follows:

- The higher productivity results from the proposed integrated ABDP-HRH followed by HRH, and finally with ABDP.
- Increasing the generator temperature from 60 to 120°C enhances the productivity of the proposed integrated ABDP-HRH from 0.466 to 2.72 m3day-1.
- Increases the productivity of HRH and ABDP increases from 0.263 to 1.52 m3day-1and from 0.234 to 1.377 m3day-1respectively.
- Higher GOR results from ABDP-HRH followed by HRH, and finally with ABDP.
- Increasing the generator temperature from 60 to 120°C increases the GOR of the proposed integrated ABDP-HRH from 2.12 to 2.38.
- The enhancement in the productivity of the proposed integrated ABDP-HRH ranging from 97.38 to 99.18 %.

Based on the survey presented in the introduction section and the results obtained in this work, the following directions for future research can be suggested as follows:

- Conducting experimental work to predict the performance of the proposed desalination plant that combines the absorption desalination cycle (ABDP) with HDH desalination plant.
- Evaluation of the performance of the proposed hybrid ABDP-HRH unit in the case of operating with waste energy.
- Investigating the possibility of recovering some of the heat coming out of the ABDP generator for the preheating of the saline water entering the HDH dehumidifier to increase the overall cycle performance.

Conflict of Interest

The authors declare no conflict of interest.

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