Journal of Solid and Fluid Mechanics (JSFM), 14(3): 5-8, 2024

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/JSFM.2024.13562.3792

Manufacturing Engineering of Iran

Thermodynamic analysis of an HDH water desalination system with a solar-driven absorption refrigeration cycle

Morteza Haddadi[1], Rouzbeh Shafaghat [2], Amirhossein Aghajani afghan [3]

[1] MSc. Student, Mechanical Engineering, Energy conversion, Babol Noshirvani University of Technology, Babol, Iran
[2] Prof., Mechanical Engineering, Energy conversion, Babol Noshirvani University of Technology, Babol, Iran
[3]Ph.D. Student, Mechanical Engineering, Energy conversion, Iran University of Science and Technology, Tehran, Iran

*Corresponding author: rshafaghat@nit.ac.ir

Received: 14/09/2023 Revised: 01/01/2024 Accepted: 23/04/2024

Abstract

A direct-contact dehumidifier and a single-effect solar absorption refrigeration system are used in this study to look at a hybrid HDH cycle. Researchers are exploring absorption refrigeration systems for their environmental friendliness, as they utilize biomass, solar, and geothermal energy for chilling. A mathematical model assessed system performance in various operational circumstances. The $\varepsilon - NTU$ correlation was used to investigate heat and mass movement in the system to add humidification and dehumidification units to the theoretical modeling. The recovery ratio (RR), coefficient of performance (COP), and output gain ratio were used to assess system performance. The hybrid HDH system and absorption refrigeration system were examined in various cooling conditions. Studies have shown that changing the amount of salty water to fresh water or dry air in an HDH system makes it possible to add a water-ammonia absorption refrigeration system without adding more cooling load. The recovery ratio improved after this change. In order to prevent the requirement for extra cooling, the system can be initiated within the range of mr_h values that are less than 2.5 and greater than 4.2.

Keywords: Direct-contact dehumidifier, single-effect solar absorption, refrigeration system, hybrid HDH, Mathematical model, Cooling conditions, Cooling load.

1. Introduction

Traditional desalination techniques, such as MSF and RO, require substantial energy usage and depend largely on fossil fuels. When the production of oil reaches its maximum level or when resources become scarcer, the prices of fossil fuels rise. Fossil fuels have the potential to make a substantial contribution to the deterioration of the environment and the contamination of the air. Consequently, utilizing solar energy to produce potable water for desalination systems will be a more appealing option. Due to the elevated operating temperature of the units in traditional desalination processes, a greater financial investment is required to provide the required energy [1]. Nevertheless, the HDH system, a form of direct solar desalination, operates efficiently without the need for high temperatures as it utilizes minimal thermal energy and can derive all the necessary thermal energy from sun radiation. Moreover, this method can be implemented in many situations on a limited scope. The components of the system are likewise affordably priced. Prior research has explored many methods to improve the process of removing moisture in the HDH cycle. This involves directly exposing the condenser to hot and humid air, as well as utilizing renewable energy sources to operate the system [2]. Multiple techniques have been investigated for the design of direct contact condensers at different scales. An attempt has been made to measure the temperature, density, humidity, and distillation in this laboratory setting [3, 4]. The research utilizes limited and transient volume analyses to analyze the condenser packings. The water or air inlet cycle of the HDH system was adjusted in specific tests to investigate its operation when a full direct condenser is present. Prior research unequivocally shows the lack of analysis and experience about HDH systems with direct contact condensers and single effect solar absorption refrigeration systems for the dehumidifier component. The utilization of absorption refrigeration technology is highly compatible with renewable energy sources, particularly solar energy [5]. Given the limited amount of research available on this topic, this work employed a mathematical model that utilized the ε-NTU correlation to do a comprehensive theoretical analysis of the HDH cycle using a single-effect solar absorption refrigeration system.

The system's performance is evaluated using performance metrics such as recovery ratio (RR), coefficient of performance (COP), and gain output ratio (GOR). Finally, several cooling scenarios and the operational state of the hybrid HDH system with the absorption refrigeration system are examined.

2. Description of the system under review

Figure 1 illustrates the diagram of the Hybrid HDH system, which integrates a solar absorption refrigeration system. For desalination, this system employs two mass and heat transfer devices, namely a humidifier and a dehumidifier. Following the dehumidification process, the resulting water is cooled using a single-effect absorption chiller evaporator powered by solar energy and then sprayed once more in the dehumidifier. The heat from the condenser heats the salt water, which then sprays onto the packing in the humidifier. This is done to enhance the humidity level in the atmosphere. The dehumidifier then conveys the heated and humid air, exposing it to a fine mist of cool, purified water. This results in the formation of liquid water from the gaseous state of water molecules in air that has a high amount of humidity. Dehumidifying humid air requires reducing its temperature to the point where water vapor condenses, leading to the formation of water droplets on the surface and the production of fresh water. After gathering the produced water from the dehumidifier section and storing it in the tank, the absorption refrigeration cycle cools a portion of it. This cooled water is then reused in the HDH cycle.

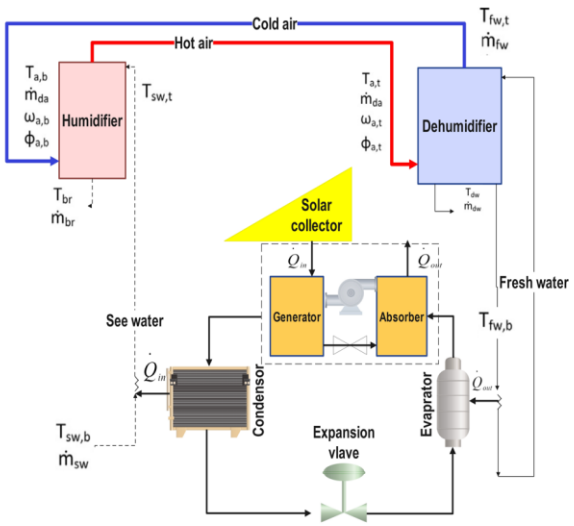

Figure 1. The hybrid HDH system with direct contact dehumidifier

In order to ascertain the assumed effectiveness of the entire setup, a thermal investigation and an examination of heat and mass transfer are carried out. Figure 1 depicts the variables employed in mathematical modeling. An investigation was conducted on the equations pertaining to balance of mass and energy for different parts of the cycle, as well as the efficiency equations for the humidifier and dehumidifier. Equation 1 and 2 are utilized to ensure mass balance in the dehumidifier and humidifier, respectively.

$$\dot{m}_{da}\omega_{a,t} = \dot{m}_{dw} + \dot{m}_{da}\omega_{a,b} \tag{1}$$

$$\dot{m}_{sw} + \dot{m}_{da}\omega_{a,b} = \dot{m}_{br} + \dot{m}_{da}\omega_{a,t} \tag{2}$$

The amount of heat that has to be extracted from the new water generated by the dehumidifier can be determined using equation 3:

$$\dot{Q}_{out} = \dot{m}_{fw} c_{p,fw} (T_{fw,b} - T_{fw,t}) \tag{3}$$

Equation 4 defines the necessary heating load for salt water.

$$\dot{Q}_{in} = \dot{m}_{sw} c_{p,sw} (T_{sw,t} - T_{br}) \tag{4}$$

Equation 5 represents the proportion of saline water entering the system compared to the amount of dry air present.

$$mr_h = \frac{\dot{m}_{sw}}{\dot{m}_{da}} \tag{5}$$

Equation 6 is used to calculate the flow ratio of entering salt water to fresh water, which can be adjusted to control the cooling loads.

$$mr_{sw/fw} = \frac{\dot{m}_{sw}}{\dot{m}_{fw}} \tag{6}$$

To numerically solve the given equations, must make some assumptions. These assumptions include that all equipment is completely thermally insulated, there is no crystallization in the chiller, and the processes of humidification and dehumidification are adiabatic [6]. The equations were solved using EES engineering software, which offers a range of thermodynamic libraries. The solution's convergence was also verified using conventional methods.

3. Results and discussion

When salt water enters the system at a specific mass flow rate, Figure 2 shows that the recovery ratio's maximum value increases with fresh water flow. In other words, as the relative flow rate of salt water entering the fresh water decreases, the recovery ratio's maximum value increases. In addition, the rise in freshwater flow resulting from the increased water demand for the dehumidifier's cooling operation also results in an escalation of the cooling load.

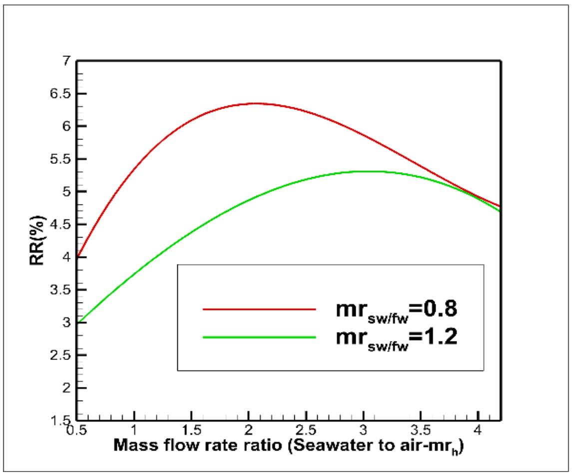

Figure 2. Effect of salt water input to fresh water on recovery ratio

The temperature of the salt water entering the humidification process causes the RR to increase by a range of 3 to 6 percent. This occurs as a result of the rise in the relative humidity of the air being emitted from the humidifier. Lowering the temperature of the fresh water used in the distillation process for dehumidification will enhance the rate of heat transfer between the water and the air. This enhances the generation of fresh water and improves the reliability and resilience of the system.

By elevating the temperature of the saltwater in the system, the quantity of water produced is augmented, leading to an increase in the GOR while maintaining a constant flow of saltwater. Additionally, this process enhances thermal recovery.

Based on the information presented in Figure 3, if the demand for cooling load from the dehumidifier is more than the supply of cooling load from the evaporator, Although the refrigeration cycle cooling load is not entirely integrated with requirements of HDH system, there is a requirement for an additional cooler.

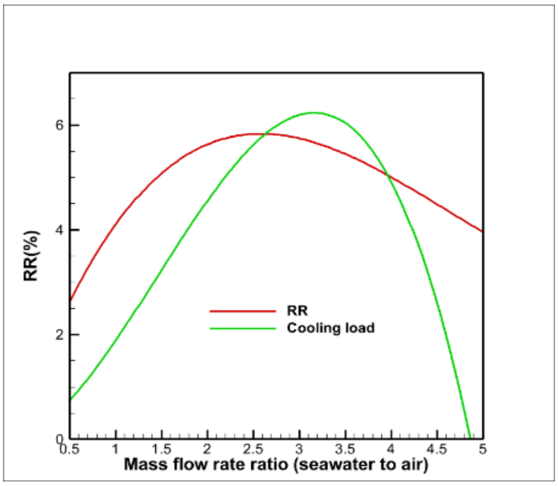

Figure 3. Cooling load of HDH system in different ratios of incoming salt water to dry air

Alternatively, it is completely integrated and does not necessitate any supplementary cooling.

By utilizing the influx of salt water, the absorption refrigeration cycle may be integrated with the entire HDH system. This will alter the efficacy of humidifiers and dehumidifiers.

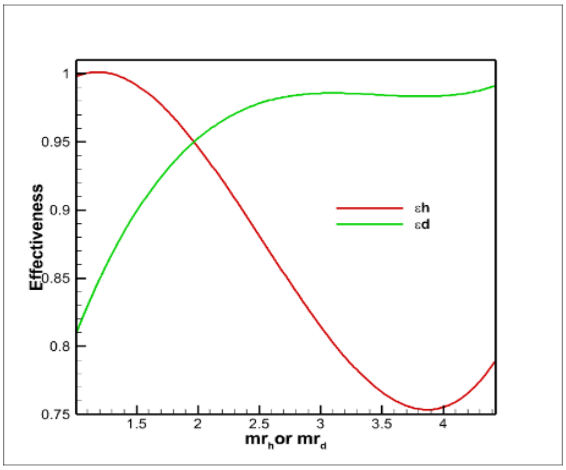

Figure 4. Comparing the efficiency of humidifier and dehumidifier in different conditions

Figure 4 shows that when the mass flow rate ratio increases, the condensation effect lowers from 1 to 0.75 and efficiency increases.

4. Conclusion

This study involved the integration of an HDH desalination system with a direct-contact dehumidifier and an absorption refrigeration cycle. The purpose was to examine and assess the system using mathematical modeling. Based on the analysis, decreasing the proportion of saltwater to freshwater enhances the air circulation inside the system and leads to an increase in the cooling load required by the system. Furthermore, as the temperature of the salt water entering the humidifier rises, the recovery ratio also increases. It has been demonstrated that raising the temperature of sea water not only increases the volume of water generated but also leads to an increase in the GOR and enhances the efficiency of the thermal recovery process. To avoid the need for extra cooling capacity from the absorption chiller evaporator, the system should be configured with a value of mr_h between 2.5 and 4.2. Additionally, the ratio of the entering salt water to fresh water was analyzed in order to assess the system's requirement for additional cooling capacity. Instead of using further cooling measures, the ratio of mass flow between salt water and fresh water can be modified.

5. References

[1] Rezaei Rad, M., R. Shafaghat, A. Aghajani Afghan, and B. Alizadeh Kharkeshi, (2023) An experimental study to evaluate the performance of an HDH water desalination system with a thermoelectric condenser. *Renewable Energy Research and Applications*.

[2] Aghajani Afghan, S., R. Shafaghat, A. Aghajani Afghan, and S.M. Hosseinalipour, (2023) An experimental study to apply an absorption refrigeration cycle as a dehumidifier in humidification-dehumidification solar desalination system. *Iranica Journal of Energy & Environment*. 14(4): p. 361-371.

[3] He, W., D. Han, and C. Ji, (2018) Investigation on humidification dehumidification desalination system coupled with heat pump. *Desalination*. 436: p. 152-160.

4] Lawal, D.U., S.M. Zubair, and M.A. Antar, (2018) Exergo-economic analysis of humidification-dehumidification (HDH) desalination systems driven by heat pump (HP). *Desalination*. 443: p. 11-25.

[5] Zhai, C. and W. Wu, (2022) Energetic, exergetic, economic, and environmental analysis of microchannel membrane-based absorption refrigeration system driven by various energy sources. *Energy*. 239: p. 122193.

[6] Sharqawy, M.H., M.A. Antar, S.M. Zubair, and A.M. Elbashir, (2014) Optimum thermal design of humidification dehumidification desalination systems. *Desalination*. 349: p. 10-21.