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A STATE OF ART REVIEW ON HUMIDIFICATION AND DEHUMIDIFICATION SYSTEM FOR SUSTAINABLE DEVELOPMENT

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Abstract

Drinking water is a necessity, yet there is only so much of it on Earth. Saline water contains the most substances on Earth yet is unfit for human consumption. The sun's energy, on the other hand, is completely free, which is why scientists are focusing on turning salt water into drinkable water. Though the production of the solar still has increased because to the efforts of many researchers, it is still insufficient for most domestic and commercial water needs. This literature study provides an overview of the work done on HDH desalination systems by researchers. Finally, the potential for the HDH desalination system to increase output in the future is discussed.

Keywords: Humidification and Dehumidification (HDH); desalination; yield; Gross output ratio (GoR).

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Introduction:

Clean drinking water is a necessity for all forms of life on Earth. Only around one percent of the water on Earth may be used for human use, such as in rivers, reservoirs, wells, etc. The growth of industry and population both contribute to a rise in the need for potable water. On the opposite side, there is plenty of salt water in the sea, but it's not drinkable. Therefore, a long-term strategy is needed to transform salt water into potable water. Desalination is a safe and effective method of removing salt from seawater. Solar desalination is one of the most important methods of desalination since it is both cost-effective and environmentally friendly.

Solar still (SS) operates in the same way that water naturally circulates through the environment, although its average output is just 3 liters per day. The SS's decreased output has attracted researchers from all around the world. In their 2017 study, Naveen Kumar et al. employed the inclined SS type and evaluated it in both day and night circumstances typical of Chennai. They determined that the daytime production increased due to the low mass of water and storage content, whereas the nighttime yield improved. Panchal et al. (2019) examined the energy and exergy using a triangular SS pyramid equipped with a baffle. They also calculated, from their trials, that the payback time for SS in the triangular pyramid shape would be 5 INR/kg. The double basin SS used by Panchal et al. (2020) utilized solid fins in conjunction with evacuated tubes to increase both surface area and yield. They looked at how it performed with and without fins and discovered that fins made a 25% difference. Shinde et al. (2019) conducted experiments to determine how a revised SS arrangement may boost yields. According to their findings, the enhanced solar design only boosts output by 17%. Panchal and Sathyamurthy (2020) examined the porous fins utilized in the SS to improve their surface area and compared them to conventional SS. The trials indicated that the average SS yield with porous fins was 3.8 liters/day, while the yield without porous fins was just 2.67 liters/day. In order to boost the evaporation rate through the bubbling effect, Joy et al. (2018) conducted experiments with air blower SS. They found that by adding the blower to the SS, thermal efficiency and production increased. Panchal et al. (2017) looked on the SS efficiency of energy storage materials. Sandstones were shown to have a greater SS production than marble when tested in patan's climate. Using a solar air heater and a base coating, Iqbal et al. (2020) examined the efficacy of SS. Water evaporation rates were improved with the invention of the solar air heater, which blows hot air over the SS base. Panchal and Patel (2017) examined the experimental findings of SS and ANSYS CFX software and found a high degree of consistency. Several techniques, including flat plate collectors, evacuated tubes, various concentrateurs, and more, were studied by Panchal et al. (2018) in an effort to increase SS production. In the end, they determined that utilizing the hot water supply in a variety of ways increased production. Panchal et al. (2017) analyzed and compared the output of several active solar stills. Abdullah et al. (2019) conducted a comprehensive review of the various SS wick-type studies. They explained the science behind the wick type SS well and the many investigations conducted by many researchers. Finally, they elaborated on future investigations into Wick type SS. Life cycle cost analysis of dual basin SS with evacuated tubes was performed by Panchal (2017) based on the experimental days of their study. When the average cost of a gallon of water was 20 Indian Rupees, the payback period was calculated to be 45 days. Yadav and Raut (2006) conducted a standard SS numerical analysis of the SS double exposure efficiency research. Double-exposure SS was proven to be significantly more effective than standard methods. The night yield of SS with evacuated pipes was examined numerically and experimentally by Vishal et al. (2019). Hot water availability improved nighttime performance using SS and evacuated tubes in thermosyphonic mode. They also discovered a high degree of agreement between experimental and numerical results. Karthik et al. (2020) used vacuum pressure supply to SS to evaluate its impact on productivity. Using a vacuum pressure of 0.6 bar in the SS, they were able to produce 5 liters daily. They also suggested using the power grid as a place to implement SS. The 2018 study by Venkatsamy et al. looked at the effects of baffles on SS in the humid circumstances of Chennai, India. They did numerical analysis, compared experimental data, and found unanimous agreement. The lowest flow rate predicted by the analyses is 0.0833 kg/min, with daily freshwater output of 3.50 kg/m2. The daily experimental production is 2,793 kg/m2. The yield is influenced by the temperature of the salt water input, which is maximum around 48.5°C. Ganaraj et al. (2018) used both internal and exterior modifications in their experimental work on double path SS. They determined that the standard SS yield was raised by 40.86 percent thanks to internal and external enhancements. In a study conducted in the climate of Gandhinagar, Gujarat, Shyora et al. (2019) compared the performance analysis of the stepped and traditional design of SS. They determined that the yield was improved by 23.88 percent using Stepped SS compared to using nature as a control. Capillary action and evaporation rates were optimized by the Tetrahedral sponge cubes in the SS, as demonstrated by Narayana and Raju (2019). They tested several sized sponge cubes and found that 5 cm was optimal for performance boosts. Nithyanadam et al. (2017) put the SS through its paces in the heat of July by throwing blue metal stones at it. They conducted tests comparing blue metal stones ranging in size from 6mm to 20mm to standard SS. Drinking water distilled in SS has been analyzed using a variety of raw water samples by Arun Kumar et al. (2019). An intriguing investigation of SS at varying salt concentrations was conducted by Dumka and Mishra (2019). They determined that 1% salt content in SS yields superior production based on theoretical and experimental observations. Indra Mohan et al. (2019) analyzed a wide range of ongoing solar designs by different teams of scientists. The Fresnel lens was used in a double-slope SS experiment by Sriram et al. (2019). Raw water for the SS experiments came from recycled industrial effluent. They came to the conclusion that potable water might be recovered from sewage by employing the Fresnel lens. Based on experimental and computational results, Shanmugan et al.(2012) analyzed the energy and exergy of SS. They discovered substantial concordance between experimental and numerical results. Multiple internal condensers for increasing the condensation rate in a solar still were investigated by Panchal and Sadasivuni (2020). Future studies on the SS and its integrated condenser were also discussed.

According to the aforementioned literature, numerous scientists have sought to improve SS's performance by the use of various components such as solar collectors, condensers, Fresnel lenses, air fans, blowers, and many more. Average daily yields of more than 10–15 liters are impossible with the ordinary SS design, which produced an average of 3 liters. In order to produce potable water, humidification and dehumidification (HDH) is the most effective method. The primary goal of this literature review is to analyze the work of various HDH researchers and to select the most effective high-yield method.

2. Various researches on Humidification and Dehumidification (HDH) desalination system

To increase the amount of desalinated water that can be produced using the HDH system, a large number of researchers from all around the world have been hard at work.

The efficiency of a hybrid dehumidification (HDH) system that includes a solar air heater and a phase change material (PCM) has been analyzed by E. K. Summers and Antar(2012). The study's primary objective was to identify the optimal PCM for maintaining a consistent solar air heater (SAH) output temperature during daylight and darkness. For the trials, they have constructed a PCM layer 8 cm thick and run tests under a variety of situations. The findings of the experiments were found to be in good agreement with those of the models. The experimental HDH system with SAH and PCM is depicted in Fig. 1.

Fig. 1 experimental setup of HDH system with SAH and PCM (Sumers and Antar 2012)

Using experimental analysis, G. Wu et al. (2017) have calculated the Gained output ratio (GoR) of the single effect HDH system. They discovered that the HDH system's GoR improved as its work output decreased. The maximum GoR was calculated using a variety of concentration ratios, and it was discovered that a greater GoR could be achieved at higher ratios. They observed the HDH's performance based on GoR through sodium chloride mass concentration and came to the conclusion that the GoR somewhat varies owing to mass concentration.

For cooling and freshwater production, T. Sachdev et al. (2020) have conducted numerical studies of a wind tower coupled with a solar air heater aided HDH desalination system running on a closed and open air water cycle. The system's efficacy has been evaluated under a range of scenarios. They also looked at how changing the water mass flow rate affected the yield from the dehumidifier of the system and discovered that a 200% increase in yield required a rate of 0.035-0.038 kg/sec. The concept of a wind tower linked to a solar air heater supporting a closed and open air water cycle HDH desalination system is seen in Fig. 2.

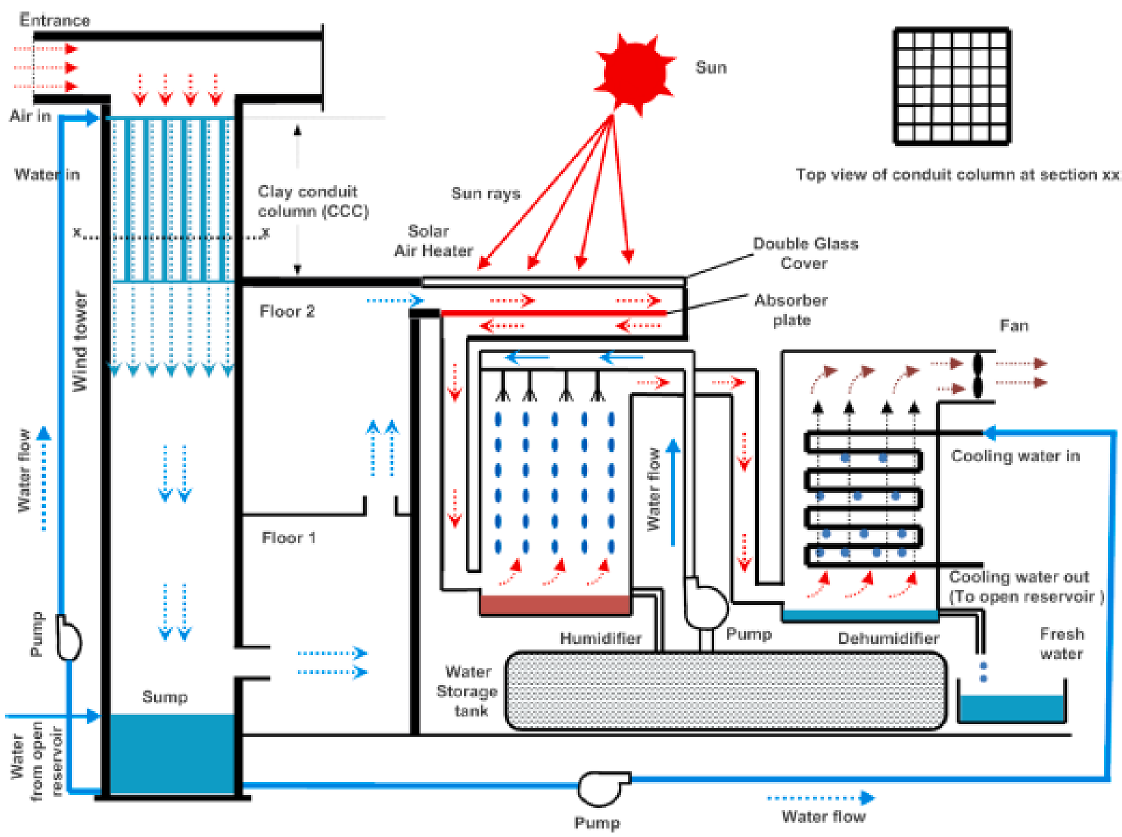

Fig. 2 schematic diagram of wind tower in combination with a solar air heater assisted HDH desalination system operating with a closed and open air water cycle. (Sachdev et al. 2020)

Small-scale direct contact HDH systems have been the subject of economic research by A. Eslamimanesh and M.S. Hatamipour (2010). They have made certain theoretical adjustments to the system in order to reap the system's energy benefits. For accurate economic analysis, they employed the COMFAR III program. The cost of the reverse osmosis (RO) facility was roughly the same as their estimate for the cost of producing potable water ($6.4/m3).

Laboratory trials of the HDH system with many inserts to boost production were conducted by Muthusamy and Srithar in 2015. In order to provide room for the mass transfer region in the present experiment, a number of inserts have been tried out in the humidifier region. The efficiency of the system has been evaluated at a flow rate of 0.340 kg/h with and without inserts. As shown in their experiments, at a flow rate of 0.340 kg/hr, the modified system with added inserts increased yield by 45 percent when compared to the standard system. Several inserts were made to the lab-scale HDH system, as shown in Fig. 3.

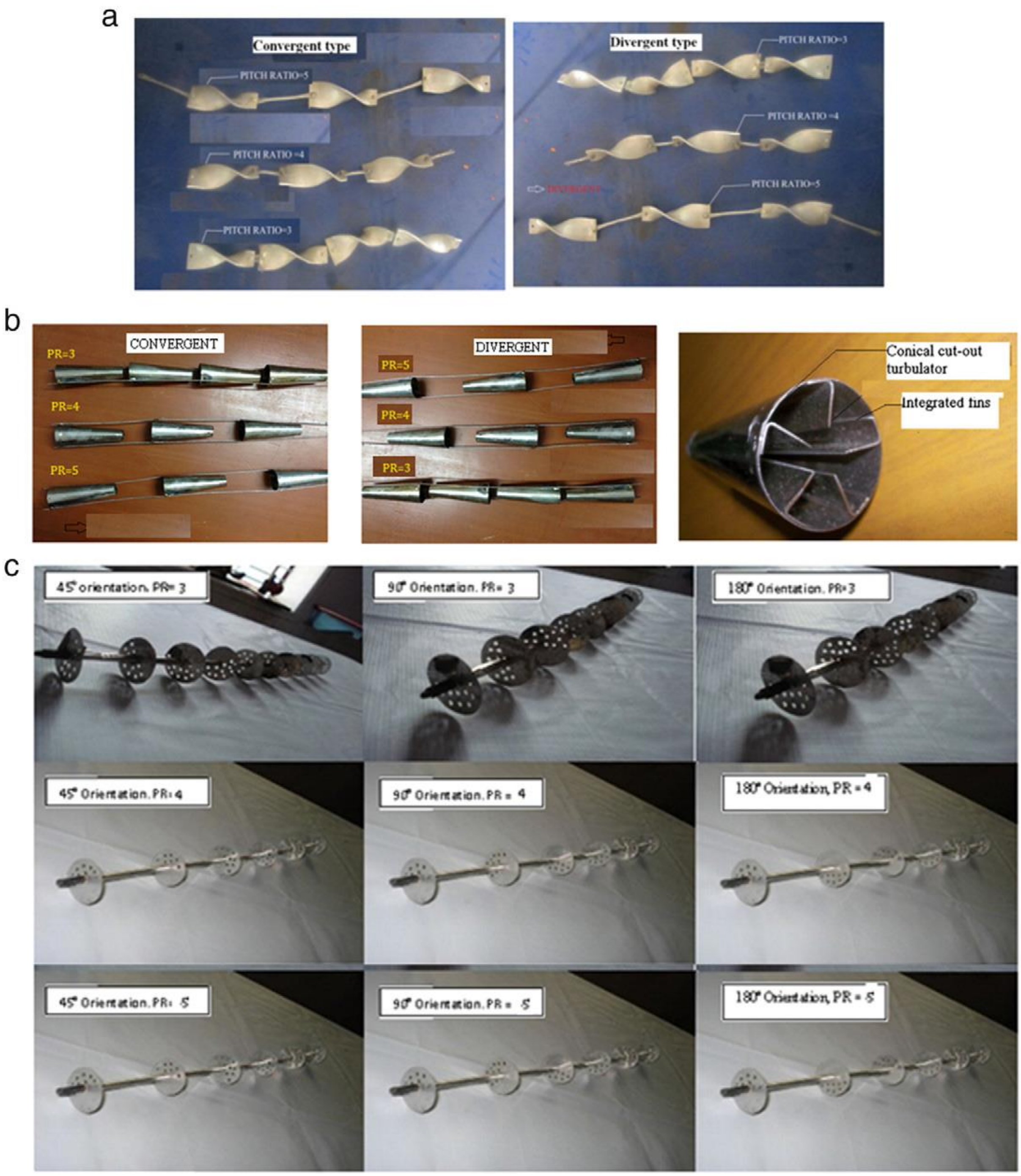

Fig. 3 Various inserts used in Laboratory scale HDH system (Muthusamy and Srithar 2015)

The new method, adapted to the EXERGY analysis of the HD desalination system in terms of driving forces by S.A. Ashrafizadeh and M. Amidpour (2012) They had investigated the exergy analysis of HDH system by use of exergy losses as driving factor in their research analysis. The phenomenon of mass transfer has no effect on the Absolute EXERGY losses of the HD systems since the inverse is the same directions to the HDH. They also established new basic equations for the analysis of EXERGY in the system, which simplifies and reduces exergy complexity of the analysis.

The efficiency of the HDH desalination system was studied by A.H. El-Shazly et al.(2012) using pulsing flow regimes. They have experimented with different flow rates, pulse rates, and other parameters to investigate how they affect the efficiency of the HDH desalination system. The results of the trials led them to the conclusion that the system's performance may be greatly improved by adding pulsing off-time in comparison to a constant water flow.

Using a number of different approaches, M. Mehrgoo and M. Amidpour (2012) calculated the optimal size of a direct contact HDH desalination system for greatest yield. In their studies, they have used a wide range of linear and nonlinear equations, as well as considered the impact of a number of different variables. Based on their findings, hot and cold water temperatures have a significant impact on the HDH system's output. The investigation also found that the specific thermal energy consumption drops when the water intake temperature is raised at the humidifier section.

The solar HDH desalination system has been evaluated by J. Wang et al.(2012) in free and forced mode under Chinese climatic conditions. The evaporation and condensation rates were tested using brackish water, which is water with a high concentration of sodium chloride. Researchers discovered that a rise in the salinity of the water led to a corresponding rise in the rates of evaporation and condensation. In the end, they determined that the cost of producing water in the forced mode, which was powered by Photovoltaic panels, was more than in the free mode.

The fixed-size HDH system, including mass extraction and injections, was studied by G.P. Thiel et al. (2013). Through thermodynamic analysis, they were able to calculate the HDH system's size. The aforementioned parameters' influence on GoR has been analyzed. The efficiency of the HDH desalination system has also been measured, both with and without the mass extraction and injections taken into account. They reasoned that since the GoR discovered an HDH system that was twice as large, the associated costs must have

The dynamic model of an HDH desalination system powered by solar energy was created by H. Ben Bacha (2013). The HDH desalination unit's behavior in a variety of climatic situations was modeled and predicted by the computer. Based on the findings, he came to the conclusion that an increase in solar intensity led to an increase in the HDH unit production. In addition to this, he came to the conclusion that increasing the air flow and water flow rate causes the output parameters of the HDH unit to decrease.

The efficiency of a two-stage, multi-effect HDH desalination system was analyzed by H. Kang et al. (2014). The current system has already successfully recycled and utilized the latent heat of condensation and the residual heat in the brine. A mathematical model of the HDH desalination system's components was also developed, and simulation results were compared. The results were found to be highly consistent with one another.

Pilot experimental configuration of novel HDH desalination system using new design of SAH and ETC was created by X. Lie et al. (2014). For the development of the novel design of SAH with HDH desalination, they had conducted a series of steady state trials. The HDH desalination system was modeled mathematically with the use of SAH and ETC, and then compared to experimental findings to ensure consistency. From their current experimental work, they deduced that a production of roughly 1000 liters per day is attainable. Fig. 4 depicts the pilot HDH desalination system's experimental set-up using the new-design SAH and ETC.

Fig. 4 experimental setup of pilot HDH desalination system with new design SAH and ETC (Li et al. 2014)

Experimental configuration of HDH desalination system using ETC was established by M.H. Hamed et al. (2015). The efficiency of the HDH desalination system was evaluated in two scenarios: with and without preheating. After four hours of labour and preheating, they obtained a 22-liter output at a cost of $0.57.80 per liter of water. They also did the mathematical modeling of the system and the experiments, and they discovered that the two were in good agreement with one another. The HDH desalination system experiment using ETC is depicted in Fig. 5.

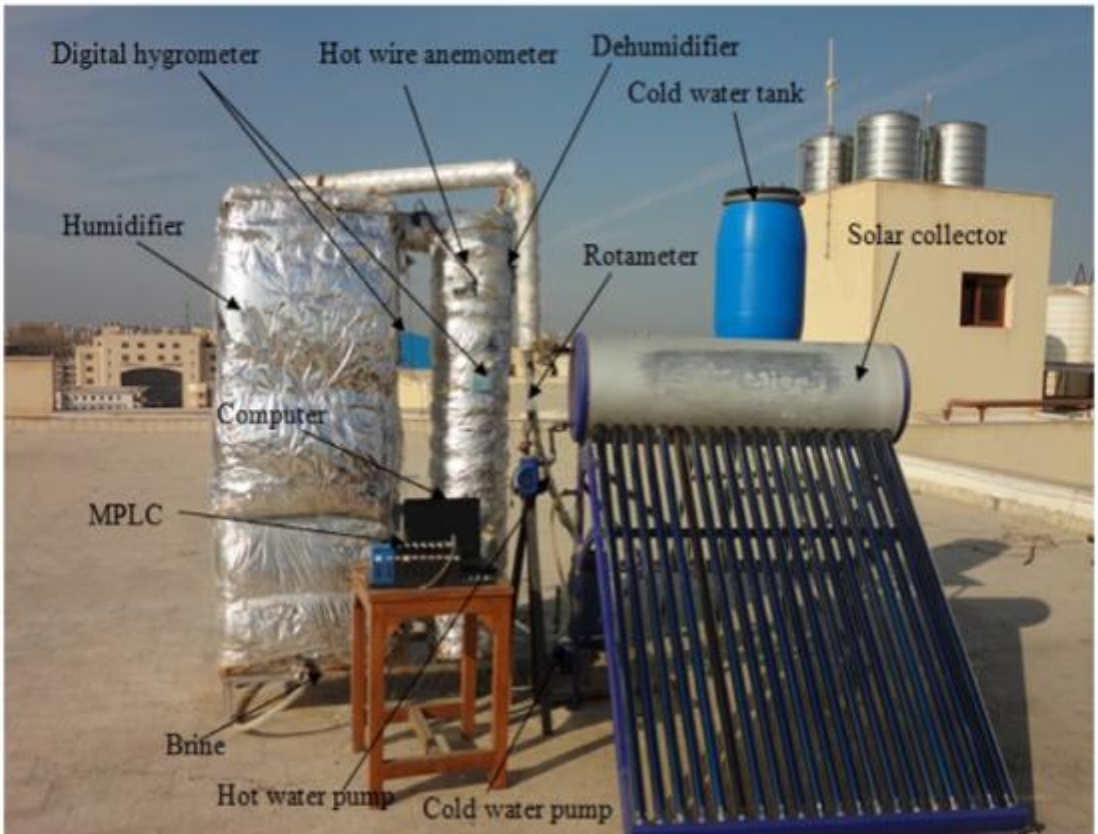

Fig. 5 Experimental setup of HDH desalination system with use of ETC (Hamed et al. 2015)

Chennai, India's environment was used to evaluate a two-stage high-density-heavy-water (HDH) desalination plant built by C. Chiranjeevi and T. Srinivas (2015). In the present study, they condensed moist air using chilled water. They compared the standard condensation method to one where cooling plant water is used to enhance the condensation process. Results from their HDH desalination studies averaged out to about 1.5 liters per hour. The HDH desalination and Cooling facility is depicted in Fig. 6.

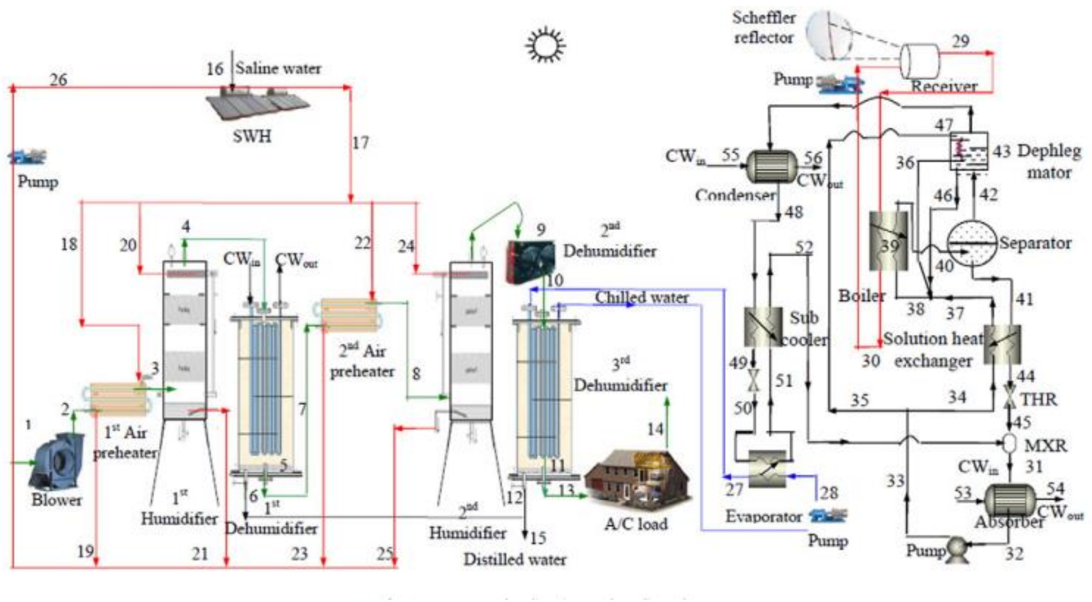

Fig. 6 Schematic diagram of HDH desalination and Cooling plant (Chiranjeevi & Srinivas 2015)

Triple effect multi effect HDH desalination system was experimentally manufactured by W. Gang et al. (2016). The highest performance rate (PR) value was recorded at 85 degrees Celsius. They also tested the effect of changing the water flow rate, and discovered that a flow rate of 2 tons per hour resulted in a yield of 182.47 liters. From their experiments, they also calculated the yield per volume to be 22 liters per cubic meter per hour. The experimental configuration of the triple effect multi-effect HDH desalination system is shown in Fig. 7.

Parametric study of the HDH desalination system was performed by C. Yldrm and I. Solmus (2014) using data from experiments and mathematical modeling. The system's efficiency was evaluated in Turkey's climatic conditions using a flat plate collector as the heat source. The system's yield was calculated and compared to the outcomes of the Runge-Kutta procedure.

The energy, exergy, economic, and enviroeconomic (4E) study of the HDH Desalination system was completed by Deniz and Cinar (2017). They carried out the performance of the system based on the information in the previous 4E paragraph, and they also evaluated the water that was collected. In the end, they also included the ongoing work that would be done on the HDH desalination plant.

In the climatic conditions of Tamilnadu, India, Rajaseenivasan and Srithar (2017) tested a laboratory size model of a biogas-powered HDH desalination system with a bubble column humidiifer. They have carried out a variety of studies making use of a variety of factors and confirmed the findings using the Taguchi technique, and they have discovered that the results only match up to roughly 8% of the time. They said that the future work will involve recovering part of the heat that was lost to the atmosphere so that it could be used again to heat the water.

Fig. 7 Experimental setup of triple effect multi-effect HDH desalination system. (Gang et al. 2016)

Experimental research was conducted by Rajaseenivasn and Srithar (2017) to explore the efficiency of the HDH desalination system while utilizing a packed bed humidifier and a unique dual purpose collector (DPC). In order to supply the HDH desalination system with heated fluids, the DPC collector has the ability to heat air and water at the same time. In order to heat the fluid, they experimented with two distinct types of turbulators, convex and concave, and compared those results to those obtained without the use of turbulators. It has been discovered that the DPC with a concave form is the optimal configuration to enhance the yield of the system based on the results of the experiments. The experimental configuration of the HDH desalination system, which makes use of DPC and a packed-bed humidifier, is depicted in Figure8.

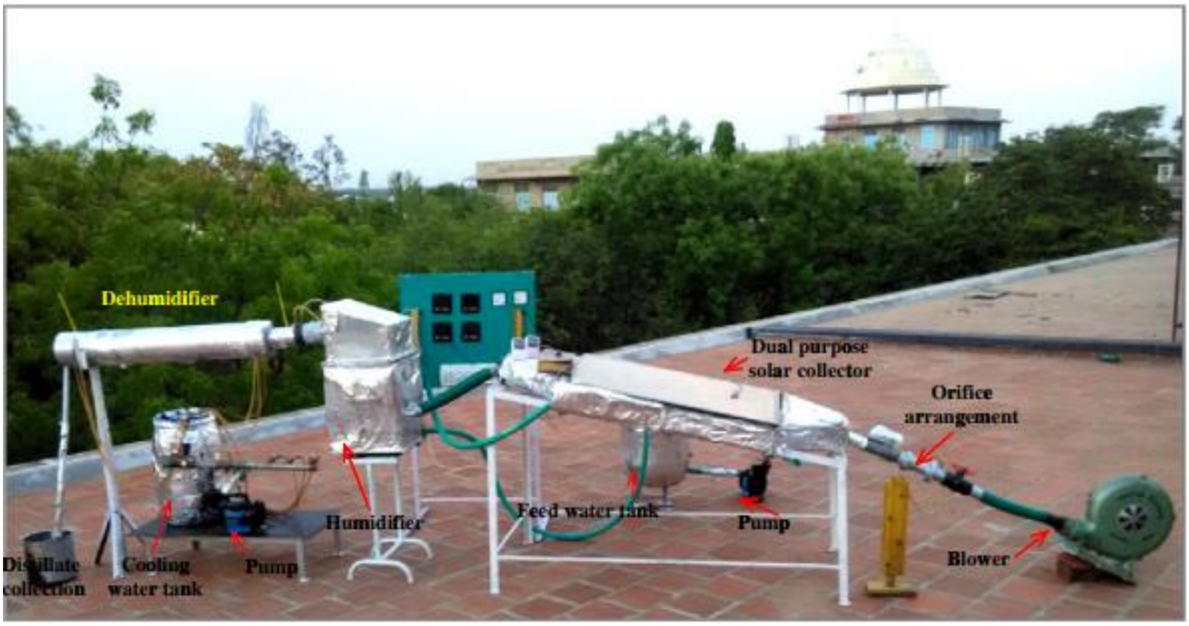

Fig. 8 experimental setup of HDH desalination system with use of DPC and packed-bed humidifier.**(Rajaseenivasan and sreethar, 2017)**

M. Faegh and M.B. Shafii (2020) utilized a unique evaporative condenser in place of a humidifier in their HDH desalination system, which contributed to the system's revolutionary design. Their research effort also included the investigation of a number of different operational parameters of the system, as well as the study of its influence on GoR. They discovered an improvement in GoR with the use of a novel evaporative condenser in the HDH desalination system, according to the findings of their experimental work. The cost of producing one liter of drinkable water using the HDH desalination system with its novel evaporative condenser was found to be $0.019 per liter.

Conclusion:

From the present review paper following points are concluded:

- HDH desalination technique is very important technique of desalination to produce water more than 10 litre per day.
- GoR is also considered as one of the most important parameter for the performance of the HDH desalination system.
- HDH desalination system requires the humidifier but it can be replaced by use of the evacuated tubes collector.

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