

Solar Humidification- Dehumidification Technology For Pure Water Production

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Abstract--- Solar desalination is gradually emerging as a successful renewable energy source of producing fresh water. This paper presents the solar humidification–dehumidification technique to produce pure water from brackish water. Units work on this principle, are considered as the most viable among solar desalination units. This study leads a step towards in the development of solar powered water purification technology. Although a fair amount of simulation studies have been conducted in the past, further design simulation is required to fully understand the complicated effects of air and water flow rates, the optimum size of individual components or modules of the unit and to generate a comprehensive model for the system.

Keywords: Humidification- Dehumidification, desalination, solar air heater, solar water heater

I. INTRODUCTION

Water and energy are two of the most important topics on the international environment and development agenda. The social and economic health of the modern world depends on sustainable supply of both energy and water. Many areas worldwide that suffer from fresh water shortage are increasingly dependent on desalination as a highly reliable and nonconventional source of fresh water. So, desalination market has greatly expanded in recent decades and expected to continue in the coming years. In the developing world, water scarcity led to the pressing need to develop inexpensive, decentralized small-scale desalination technologies that use renewable resources of energy. This study reviews one of the most promising of these technologies, humidification–dehumidification (HDH) desalination powered by solar energy. The different types of HDH cycle design and its constituents (humidifier, solar heaters, and dehumidifiers) have been investigated. The review also includes water sources, demand, availability of potable water and purification methods. It is concluded that HDH technology is a promise process for decentralized small-scale water production applications, but it needs additional research and development to enhance the system efficiency and economy.

A. Principal of humidification-dehumidification processes (HDH)

The most promising recent development in solar desalination is the use of the humidification–dehumidification (HD) process. The HD process is based on the fact that air can be mixed with large quantities of water vapor. The vapor carrying capability of air increases with temperature: 1 kg of dry air can carry 0.5 kg of vapor and about 670 kcal when its temperature increases from 30°C to 80°C.

When flowing air is in contact with salt water, a certain quantity of vapour is extracted by air, which provokes cooling. Distilled water, on the other hand, may be recovered by bringing the humid air in contact with a cooled surface, which causes the condensation of part of the vapour in the air. The condensation occurs in another exchanger in which salt water is preheated by the latent heat of condensation. An external heat contribution is therefore necessary to compensate for the sensitive heat loss [1].

The HD technique is especially suited for seawater desalination when the demand for water is decentralized. Several advantages of this technique can be presented which include flexibility in capacity, moderate installation and operating costs, simplicity, and possibility of using low-grade thermal energy (solar, geothermal, recovered energy or cogeneration). In this process, air is heated and humidified by the hot water received from a solar collector. It is then dehumidified in a large surface condenser using relatively cold saline feed. Most of the latent heat of condensation is used for preheating the feed.

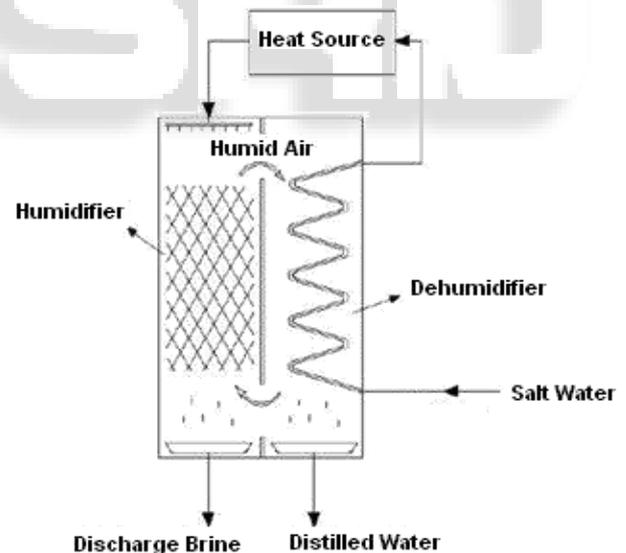


Fig. 1

B. Principle of Humidification Process

1) Performance parameters of hdh process

The performance parameters for Solar Humidification–Dehumidification process are defined by G. Prakash Narayan and et al. [2] as follows:

2) Gained Output Ratio (GOR)

GOR is the ratio of the latent heat of evaporation of the water produced to the heat input to the cycle. This parameter is, essentially, the effectiveness of water production and an index of the amount of the heat recovery effected in the

system. Latent heat is calculated with the operating pressure assumed as saturation pressure.

3) *Top Temperature*

In HDH systems, either water or air is heated (for example, in a solar collector). The top temperature of the cycle is the temperature of the fluid being heated at the exit of the heater.

4) *Bottom Temperature*

The feed water to the dehumidifier enters the cycle at the bottom temperature of the cycle.

5) *Terminal Temperature Difference (TTD)*

TTD is the stream to stream temperature difference at either end of the heat exchanger (humidifier /dehumidifier)

A. *Pinch Point Temperature Difference (P)*

Pinch point temperature difference is the minimum local stream-to-stream temperature difference at any point within the heat exchanger and is lower than both the terminal temperature differences. In some cases, however, the pinch can be equal to one of the terminal temperature differences.

6) *Heat Capacity Ratio (HCR)*

For heat and mass exchange devices like the humidifier and the dehumidifier, we had previously defined a parameter called the modified heat capacity ratio. The modified heat capacity ratio is the ratio of maximum possible enthalpy change of the cold stream to the maximum possible enthalpy change of the hot stream.

II. TYPES OF HDH SYSTEMS

HDH systems are classified under three broad categories according to type of energy used, cycle configuration, and type of heating systems.

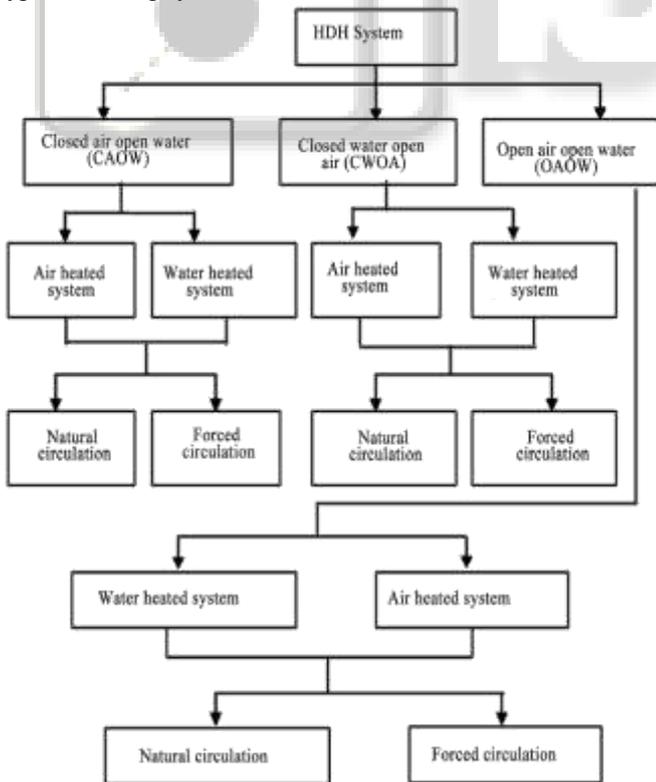


Fig. 2

HDH systems can be classified based on the form of energy used such as solar, thermal, geothermal, or hybrid systems. This classification brings out the most promising merit of

the HDH concept; the promise of water production by use of low grade energy, especially from renewable resources.

Based on the cycle configuration HDH systems are classified, into closed air open water, closed water or open air open water systems [3]. In all these configurations the flow can be either forced or natural as shown in Figure 2 [4].

Classification of HDH Systems based on the Cycle Configuration [4]

Based on the stream to be heating, HDH systems are classified into air heated or water heated systems. The performance of the system depends greatly on whether the air or water is heated and this will be discussed in the following subsections. While there are many decades of experience and wisdom on solar water heating devices, relatively little work has been done on the solar collectors for air heating considering their importance to the overall HDH system performance.

A. *Closed water- Open Air (CWOA)*

In a CWOA cycle the closed-water circulation is in contact with a continuous flow of cold outside air in the evaporation chamber as shown in Figure 3. The air is heated and loaded with moisture as it passes upwards through the falling hot water in the evaporation chamber. After passing through a condenser cooled with cold seawater, the partially dehumidified air leaves the unit, while the condensate (distillate) is collected. The water is recycled or re-circulated. Incoming cold air provides a cooling source for the circulating water before it re-enters the condenser. The productivity of units working on this principle is high, but the power required for the circulation is also very high. One disadvantage of CWOA cycle is that when the humidification process does not cool the water sufficiently, the water temperature to the inlet of the condenser is higher, resulting in lower air dehumidification and lower water production. However, in the case where efficient humidifiers are used, cooling the water as low as possible up to the limit of the ambient wet-bulb temperature, the closed water system yields more water than the open water system [5].

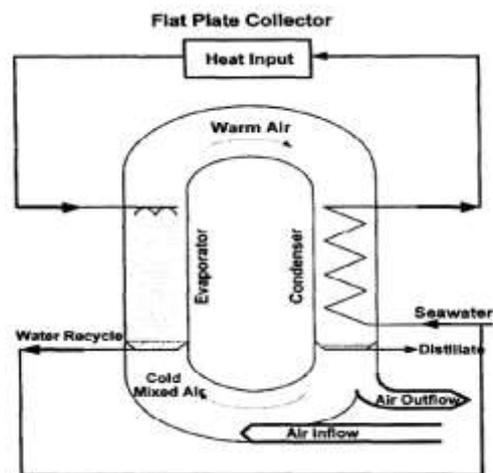


Fig 3: Closed Water-Open Air Cycle [5]

B. *Closed Air-Open Water (CAOW)*

In a CAOW cycle the humidifier is irrigated with hot water and the air stream is heated and humidified using the energy from the hot water stream. The humidified air is cooled in a

heat exchanger using seawater as a coolant. The seawater gets preheated in the process and is further heated by a heat source before it returns to the humidifier. The dehumidified air stream from the condenser is then circulated back to the humidifier. For the closed air, water heated cycle natural circulation of air yields better efficiency than forced circulation of air.

The performance of system heavily depends on whether the air or water is heated. There is extensive knowledge of solar water heating device but relatively little work has been done on air heating solar collectors.

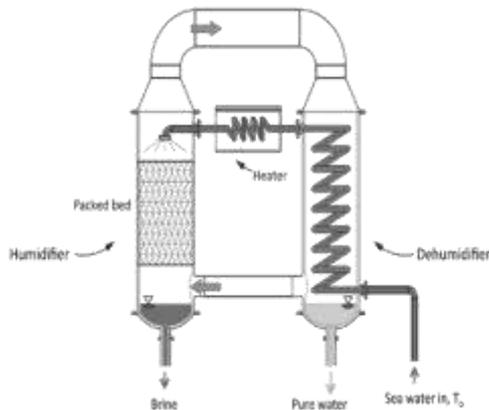


Fig. 4: Closed Air-Open Water Cycle [5]

Typically, air-heated systems have higher energy consumption than water heated systems because in the air-heated cycle the air heats up the water in the humidifier and this energy is not subsequently recovered from the water.

On the other hand, in the water-heated cycle, the water stream is cooled in the humidifier and the energy is transferred or recovered in the air stream. Enhanced latent heat recovery is needed to minimize the energy consumption and the resulting cost of these cycles [7].

C. Open Air- Open water (OAOW)

Open-air, open-water (OAOW) cycle is formed when water and air stream forms a single pass through the system as shown in Figure 5. Here air may heat, water may heated or both may be heated at their inlets.

III. COMPONENTS OF HDH PROCESS

There are three main components in the solar HDH system: humidifier, dehumidifier and solar thermal heater (for air, water or for both).

A. Humidifiers

It is where air comes in contact with water and humidified. The aim of the humidifier is to increase the area and time of contact between water and air. There are several types of humidifiers; bubble column, wetted wall tower, packed bed tower, spray tower. In the humidifier of HDH system, the air holds water vapor when hot water is sprayed and the air is needed to be humid as much as possible. The principle of operation for all of these devices is the same. When water is brought into contact with air that is not saturated with water vapor, water diffuses into the air and raises the humidity of the air. The driving force for this diffusion process is the concentration difference between the water-air interface and the water vapor in the air. This concentration difference

depends on the vapor pressure at the gas-liquid interface and the partial pressure of water vapor in the air.

To increase the humidification efficiency, packing is typically used. Since it increases the dispersion of water droplets, the contact area and contact time. Devices that contain packing material are known as packed bed towers and special types that are used to cool water are called cooling towers.

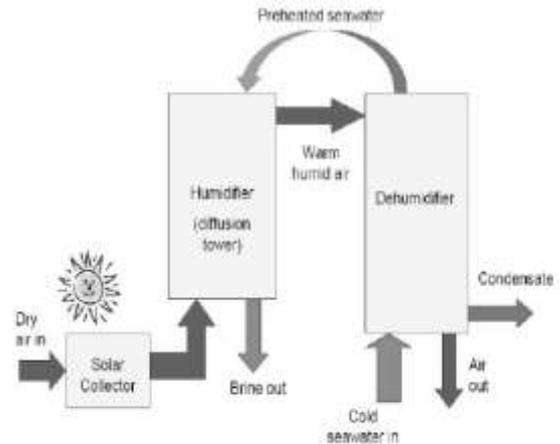


Fig. 5: Air-heated Cycle

These packed beds are simply as vertical columns filled with packing materials and water is sprayed at the top while air flows in counter or cross- flow arrangement. Packed bed towers have been used by many researchers as a humidifier device in HDH desalination systems because of the higher effectiveness. Different packing materials have been used as shown in Table 1.

Author	Packing Material
Amer et al.[8]	Wooden, pvc, Gunny bag cloth
Hermosillo et al [9].	Cellulose paper
Yamali et al. [10]	Plastic packing
Yuan G., Zhang H. [11]	Honeycomb paper
Eslamimanesh A., Hatamipour M. [12]	Rasching ring ceramic
Hou S., Zhang H. [13]	Wooden slates packing
Farsad S., Behzadmehr A. [14]	Wooden slates packing

Table 1: Packing Materials

B. Dehumidifiers

For the design of a thermal system, it is often necessary, for selection purposes, to predict the heat transfer rates of heat exchangers under specific operating conditions. Heat exchangers are complex devices, the complexity being due to both to the geometry and to the physical phenomena involved in the transfer of heat. Many experimental studies have been carried out to study the heat and mass transfer characteristics of the dehumidifying heat exchangers.

In order to utilize the latent heat of condensation of water efficiently, the condenser area must be made large. The overall heat transfer coefficient of the condenser is expected to be small due to:

- 1) The low velocity of the air circulated in the unit, even in forced circulation which was necessary to avoid excessive pressure drop.
- 2) The large reduction in the condensation heat transfer coefficient due to the mass transfer

resistance occurring in the process of condensation of water vapor with non-condensable air.

- 3) The low water side heat transfer coefficient due to the low water flow rate per unit condenser area.

The dehumidifier is the apparatus where the water vapor in the humidified air is condensed producing the fresh water. There are two types of dehumidifiers; direct contact dehumidifiers, indirect contact dehumidifiers and thermally coupled humidifier dehumidifier.

C. Air Heaters

Solar water heating systems have been studied and used widely for many decades and hence extensive knowledge exists on the design of these systems. It is found that performance of solar air heating systems improve the overall performance of solar HDH system. The collectors are typically flat plate with large airflow channels. Air flows over or under the absorber plate, and double-pass strategies are sometimes employed. Figure 6 shows the layout of an air heating collector. The absorber plates in air collectors can be metal sheets, layers of screen, or non-metallic materials. The air flows past the absorber by using natural convection or a fan.

B. Water Heaters

A flat-plate solar collector is one of main types of solar collectors, which are key components of active solar heating systems. The other main types are evacuated tube collectors and batch solar heaters (also called integrated collector-storage systems). A flat-plate collector consists basically of an insulated metal box with a glass or plastic cover (the glazing) and a dark-colored absorber plate. Solar radiation is absorbed by the absorber plate and transferred to a fluid that circulates through the collector in tubes. In an air-based collector the circulating fluid is air, whereas in a liquid-based collector it is usually water.

The rate of water distillation can be increased with the help of concentrating collector like parabolic trough and parabolic dish type. Little research work is found on HDH process with concentrating solar water heaters.

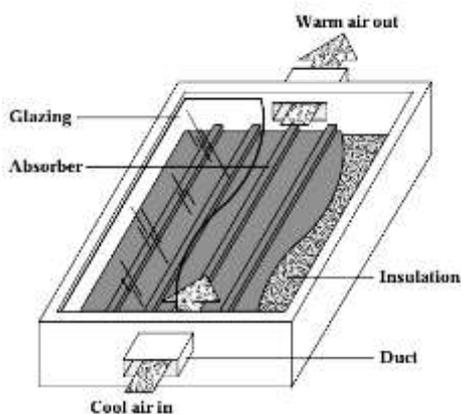


Fig. 6: Solar Air Heater

IV. CONCLUSION

Solar HDH technology has been reviewed in this paper. From the present review, it is found that the humidification-dehumidification desalination process HDH will be a suitable choice for pure water production when the demand is decentralized. HDH is distinguished by simple operation

and maintenance. Although a fair amount of simulation studies have been conducted in the past, further design simulation is required to fully understand the complicated effects of air and water flow rates, the optimum size of individual components or modules of the unit and to generate a comprehensive model for the system.

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