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# A Review on Solar Air Heater Assisted Water Evaporating System Using HDH Process

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## ABSTRACT

Future global development will be hampered by two main problems: a shortage of clean water and functional energy. These problems also have a big effect on how any country's economy and society are changing generally. Conventional desalination techniques are typically associated with large-scale, technologically complex systems. With the use of different solar collector, we can save energy and decreases dependency on energy produced by fossil fuel. Since these solar heaters can make up over 40% of the total cost of a humidification-dehumidification (HDH) system, developing a cost-effective and efficient solar collector is essential to the system's functioning.

Keywords: Solar air heater, Humidification, Dehumidification

## I. INTRODUCTION

Because of the rapid growth of the agricultural and industrial sectors as well as the population, a clean water supply has become essential to life. The fresh water levels in many reservoirs are dangerously low. Waste water from factories, plants, and big city sewage has contaminated the remaining freshwater sources. Seawater makes up 97% of the planet's water, with fresh water comprising 0.5% and glaciers and ice caps making up 2%. The earth contains water.

Obtainable drinking water has become a limited resource. India has a lot of seawater. The industrial development contaminated the water. As a result, desalination is increasingly important as a freshwater production technique. A few advantages of the humidification-dehumidification (HDH) process for water desalination are its decentralized application, simplicity, low operating costs, ease of installation, and capacity flexibility.

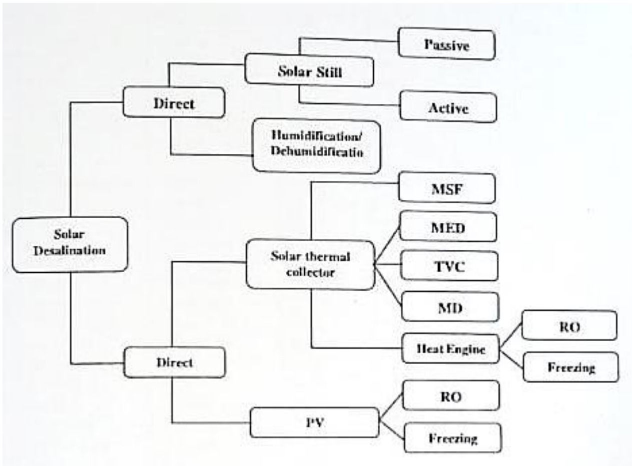


Fig.1.1 Pilot tested Solar Desalination technologies

Over the course of a year, latitude has a major influence on both the total amount and intensity of solar radiation. The Tropic of Capricorn passes through Gujarat, and its annual average monthly isolation is evenly distributed. With 1500–2000 sunshine hours annually, the daily average solar energy incident over India varies depending on location. Over 5.25 kwh/m$^2$ of total solar insolation occurs every day in Gujarat.

In order to achieve the maximum rate of evaporation for unit area of solar collectors, the proposed research project combines the efficient design of solar collectors with the humidification method of evaporation. This explores the possibility of using low temperature energy sources, such as solar energy. Fig 1.1 shows different solar desalination technologies.

## II. LITERATURE REVIEW

### 1.1 Humidification-dehumidification (HDH) desalination technology:

Nature uses solar energy to desalinate ocean water through the rain cycle (Fig. 2.1). Seawater functions as a carrier gas in the atmosphere by heating up due to solar radiation and becoming humid during the rain cycle. The humid air rises after that and forms clouds. Eventually, the clouds "dehumidify" and start to pour. This cycle is artificially created and is known as the humidification dehumidification cycle (HDH cycle).

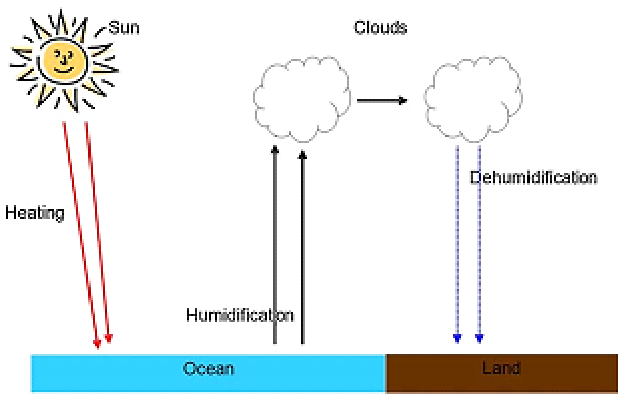


Fig 2.1 Rain Cycle [34]

### 1.2 Principle of The Humidification–Dehumidification (HDH) Process:

Bourouni has looked at the foundations of the HD process. The basis of the HD process is the capacity to mix air with substantial volumes of water vapor. Air has a vapor carrying capacity that varies with temperature. For instance, when dry air temperature increases from 30°C to 80°C, one kilogram of vapor and approximately 670 kcal can be carried by one kilogram of dry air. When air comes into contact with salt water, some of the vapor is drawn out by flowing air, which results in cooling. In contrast, some of the vapor in the humid air will condense when it comes into contact with a cooled surface, producing recovered distilled water.

The condensation typically occurs in a different exchanger due to the latent heat of condensation, which warms the salt water. To counteract the sensitive heat loss, an external heat contribution is necessary. The HD technique is especially effective at desalinating seawater when there is a decentralized demand for water.

### 1.3 Classification of typical HDH processes (based on cycle configuration) [34]

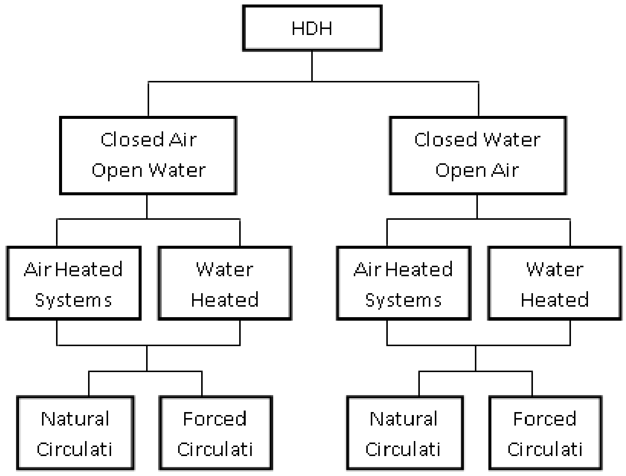


Fig 2.3 Classification of typical HDH processes

#### 2.3.1 Closed-air open-water (CAOW) water-heated systems:

The humidifier receives irrigation from hot water, and the hot water stream's energy is utilized to heat and humidify the air stream. The humidified air is then sent to the dehumidifier, where it is cooled using a small heat exchanger that uses seawater as the coolant. The seawater is preheated and then heated some more in a solar collector before it irrigates the humidifier The dehumidified air stream is circulated back to the humidifier from the dehumidifier.

#### 2.3.2 Closed-water open-air (CWOA) water-heated systems:

The humidifier in this system heats and humidifies the air by using hot water from the solar collector. The air is then dehumidified using the humidifier's output water. After being preheated in the dehumidifier, the water enters the solar collector operating in a closed loop. The dried air is released back into the environment. At room temperature, air enters the humidifier saturated, after which it travels in the dehumidifier. The air becomes less humid at the saturation line.

### 2.3.3 Closed-air open-water (CAOW) air-heated systems

Another class of HDH systems that has attracted a lot of interest is the air-heated system. These systems come in two varieties: single-stage and multi-stage systems. The air is directed to a humidifier after being heated in a solar collector to a temperature of 80 to 90 degrees Celsius. In the humidifier, the air is cooled and saturated. It is then cooled and dehumidified. The lowest possible absolute humidity of air (less than 6% by weight) at these temperatures is the main disadvantage of the cycle. This lowers the water productivity of the cycle.

### 2.3.4 Air-heated CWOA HDH process:

The air that has been heated in the solar collector. The evaporator's humidified air In the condenser, it becomes dehumanized. In addition, water distribution networks are widely used, even in remote and sparsely populated areas. It is very difficult to develop and apply new technologies because of these obstacles. The continuous use of large-scale, dependable multi-stage flashing desalination plants (MSF) is another important factor.In spite of this, MSF plants are expensive, particularly when paired with a large-scale water distribution system. Additionally, the RO process requires sophisticated technological capabilities for module preparation and membrane synthesis. Additionally, feed pretreatment for the RO process is usually necessary and intensive.

## 2.4 Development and use of New Technologies:

It is very desirable for plants with small capacities. However, pilot scale units and early prototypes might not be the best option in the end. Desalination process which is dependable, affordable, and efficient might be partially or entirely developed. These methods include using different kinds of heat pumps in conjunction with more energy-efficient heating and cooling systems, utilizing renewable energy sources.

The conceptual design of several schemes for water desalination using the humidification/dehumidification system (HDH) is the main focus of this study. Both remote areas with sparse populations and industrial sites may find this design appropriate. A thorough analysis of earlier research in the field reveals that a significant portion of these studies are devoted to assessing the performance of the HDH system in conjunction with solar energy.

Vlachogiannis et al. present a novel concept that involves mechanical compression followed by air humidification. According to reports, this configuration has a very high specific power consumption that is nearly 100 times higher. The condenser cools the humidified air to condense the water, the humidifier raises the humidity of the intake air to saturation levels. The dehumidification unit preheats the seawater intake. The feed heater continues to heat the seawater feed.

This is produced using an external heat source, such as a diesel engine, solar collector, steam boiler, or other low-grade energy source. The humidifier, condenser, and heater designs are all analyzed in the conventional HDH. It is believed that the air stream is saturated as it exits the condenser and humidifier.

A study on the development of the HD technique for water desalination in India's arid zones was reported by Garg et al. [28] in 1968. Depending on variations in solar radiation intensity, a solar still developed in the first stage at the Central Salt and Marine Chemicals Research Institute, Gujarat, India, produced 2.94–3.91 L/m$^2$ of still area. The solar-powered HD technique addressed some of the shortcomings of the solar still technique. Early on in the HD technique's development, an experimental unit with a capacity of 3 L/d (24 hours) was produced. The brine was heated with an electric heater. Based on experimental runs, a liquid-gas ratio (L/G) of about 3 was found to be appropriate for lower temperatures, about 550°C. At a brine temperature of 60°C, that unit produced 3.4 L/d.

A techno-economic analysis of an air HD desalination process was carried out by Khedr [2]. The findings demonstrated that condensation recovers 76% of the energy used by the humidifier. The HD process can operate with an output as low as 10 $m^3/d$ and has a great deal of potential as a substitute for small-capacity desalination plants. Raising the water temperature at the humidifier's inlet on the MEH unit resulted in an increase in desalination productivity. Air circulation was also discovered to be crucial for improving system performance. A test rig for a MEH solar desalination plant based on the humidification principle was built by Madani and Zaki [1]. On a normal summer day at noon, the unit produced 0.63–l.25 $L/m^2$ h of fresh water (2.5–5 $L/m^2$ d for a 4 h/d peak time operation), which is comparable to some effective single-basin stills.

**Humidification chamber:[34]**

A variety of equipment, such as spray towers, bubble columns, wet wall towers, and packed bed towers, are used to humidify air [6]. Every one of these devices operates on the same principle. Water diffuses into air and increases air humidity when it comes into contact with air that is not saturated with water vapor. The concentration differential between the water vapor in the air and the water-air interface acts as the driving force behind this diffusion process. The partial pressure of water vapor in the air and the vapour pressure at the gas-liquid interface determine this concentration difference. Any of the above-mentioned devices can be used as a humidifier in the HDH system. For example, a spray tower is essentially a cylindrical vessel with a continuous air stream flowing upward and water sprayed at the top of the vessel, which moves downward by gravity and disperses into droplets. These towers have a small gas side pressure drop and a straightforward design. Nonetheless, the spray nozzles cause a significant pressure drop on the water side. Furthermore, because of the air leaving the tower's propensity to entrain water, mist eliminators are always required.

The low water holdup resulting from the loose packing flow is the cause of the low efficiency [7]. One crucial factor in the design of a spray tower is the diameter-to-length ratio. The spray and air will be well combined for a large ratio. A small ratio of diameter to length will allow the spray to reach the tower walls quickly, forming a film that will render it useless as a spray. The contact surface area of the water droplets as well as the mass transfer and heat coefficients must be understood in order to design the 21 spray towers.

**2.5 Dehumidification chamber:[34]**

The types of heat exchangers used as dehumidifiers for HDH applications vary. For example, flat-plate heat exchangers were used by Müller-Holst et al. [17]. Others used finned tube heat exchangers ([16], [18] & 12]). A long tube with longitudinal fins was used in one study [21], while a stack of plates with copper tubes mounted on them in another study ([22] & [23]) used a horizontal falling film-type condenser. Direct contact 25 heat exchangers were also used as a condenser in some other studies [24] in combination with a shell and tube heat exchanger to provide enhanced condensation and improved heat recovery for the cycle. To dehumidify the air, a heat exchanger is added at the seawater intake (low temperature level). The heat exchangers, also known as dehumidifiers, are air coolers with finned tubes.

**2.8 Solar collectors**

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air. water. or oil) flowing through the collector.

There are basically two types of solar collectors: non-concentrating or stationery and concentrating.

**Table.2.1 Solar energy collectors**

| Motion | Collector type | Absorber type | Concentration ratio | Indicative temperature range (°C) |
|---|---|---|---|---|
| Stationary | Flat plate collector (FPC) | Flat | 1 | 30-80 |
| | Evacuated tube collector (ETC) | Flat | 1 | 50-200 |
| | Compound parabolic collector (CPC) | Tubular | 1-5 | 60-240 |
| Single-axis tracking | | | 5-15 | 60-300 |
| Two-axes tracking | Linear Fresnel reflector (LFR) | Tubular | 10-40 | 60-250 |
| | Parabolic trough collector (PTC) | Tubular | 15-45 | 60-300 |
| | Cylindrical trough collector (CTC) | Tubular | 10-50 | 60-300 |
| | Parabolic dish reflector (PDR) | Point | 100-1000 | 100-500 |
| | Heliostat field collector (HFC) | Point | 100-1500 | 150-2000 |

**2.8.1 Stationary collectors [37][38]**

Solar energy collectors are basically distinguished by their motion, i.e. stationary. These collectors are permanently fixed in position and do not track the sun. Three types of collectors fall in this category:

1. Flat plate collectors (FPC);
2. Stationary compound parabolic collectors (CPC);
3. Evacuated tube collectors (ETC).

**2.8.1.1 Flat-plate collectors**

Fig. 2.8 depicts a typical flat-plate solar collector. A significant amount of the energy from the sun is absorbed by the plate and transferred to the transport medium in the fluid tubes so that it can be used or stored when it passes through a transparent cover and strikes the blackened absorber surface of high absorptivity. To minimize conduction losses, the side of the casing and the underside of the absorber plate are both well insulated. The liquid tubes may be integrated into the absorbing plate. The transparent cover helps to lower convection losses from the absorber plate. Additionally, it lessens radiation losses from the collector because, although the glass is nearly opaque to long-wave thermal radiation emitted by the absorber plate (the greenhouse effect), it is transparent to short-wave radiation received by the sun.

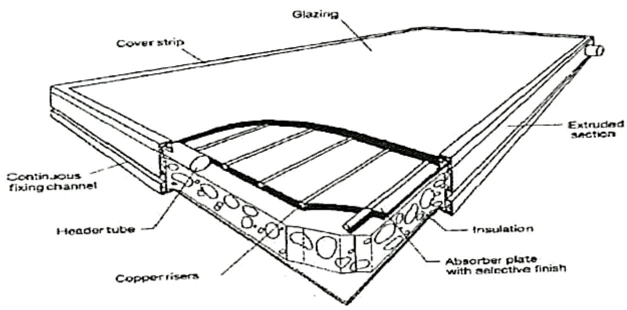


Fig. 2.8 Pictorial view of a flat-plate collector

glazing components. Because glass can transmit up to 90% of the incoming shortwave solar irradiation, it is frequently used to glaze solar collectors. plates that absorb collectors. Through the glazing, the collector plate absorbs as much radiation as possible, losing as little heat as possible through the back of the casing and upward to the atmosphere. The heat that is retained is transferred to the transport fluid by the collector plates. Commercial solar absorbers are now produced via electroplating, anodization, evaporation, sputtering, and the application of solar selective paints. Traditionally, black is utilized.

**2.8.1.2. Compound parabolic collectors** [38]

CPC concentrators can reflect all incident radiation back to the absorber. Winston, the collector, made a point about their potential as solar energy collectors. There are several possible configurations for the absorber. It may be flat or cylindrical. The lower (AB and AC) and upper (BD and CE) portions of the reflector in the CPC depicted in Fig. 2.9 are circular and parabolic, respectively. Since a CPC's upper portion doesn't contribute much to the radiation that reaches the absorber, it is typically truncated to create a shorter, less expensive version of the CPC. In order to prevent dust and other materials from getting inside the collector and lowering the reflectivity of its walls, CPCs are typically covered with glass.

A CPC concentrator's aperture is tilted directly towards the equator at an angle equal to the local latitude, and its long axis can be oriented in either a north–south or an east–west direction. The collector must continuously face the sun when oriented in a north-south direction by rotating its axis in that direction.

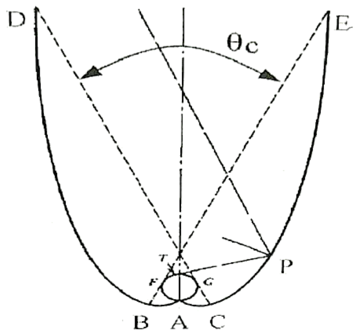


Fig. 2.9 Schematic diagram of a compound parabolic collector.

**2.8.1.3. Evacuated tube collectors**

ETC transfers heat efficiently by using materials that undergo liquid vapour phase change. A heat pipe, a very effective thermal conductor, is positioned inside a vacuum-sealed tube in these collectors. After that, a black copper fin that fills the tube (absorber plate) is connected to the sealed copper pipe. Each tube has a metal tip that protrudes from the top and is connected to the sealed pipe (condenser). A tiny amount of fluid (such as methanol) that goes through an evaporating-condensing cycle is contained in the heat pipe. This cycle begins with the liquid being evaporated by solar heat. The vapour then moves to the heat sink region, where it condenses and releases latent heat. The procedure is then repeated with the condensed fluid returning to the solar collector. The metal tips up when these tubes are installed inside a heat exchanger (manifold). Heat from the tubes is transferred from the manifold to water, or glycol. After passing through another heat exchanger, the heated liquid transfers its heat to water kept in a solar storage tank or to a process. The heat pipe provides built-in protection against freezing and overheating since there can be no evaporation or condensation above the phase-change temperature. The evacuated heat pipe collector's self-limiting temperature control is one of its special features.

**2.8.2. Sun tracking concentrating collectors**: [36][37][38]

Reducing the area from which the heat losses occur will raise the temperatures at which energy delivery occurs. If a significant amount of solar radiation is focused on a small collection area, temperatures that are significantly higher than those that are possible with FPC can be attained. This is accomplished by placing an optical device in between the radiation source and the surface that absorbs energy.

The collectors falling in this category are:

1. Parabolic trough collector;
2. Linear Fresnel reflector (LFR);
3. Parabolic dish;
4. Central receiver.

**2.8.2.1. Parabolic trough collectors**

It takes a high-performance solar collector to deliver high temperatures with good efficiency. With parabolic through collectors (PTCs), systems with lightweight constructions and inexpensive technology for process heat applications up to 400°C could be achieved.

A sheet of reflective material is bent into a parabolic shape to create PTCs. A glass tube covering a metal black tube is positioned along the receiver's loca11 line to minimize heat losses (Fig. 2.10). Parallel rays incident on the reflector are reflected onto the receiver tube when the parabola is oriented towards the sun. Long collector modules are created because a single axis tracking of the sun is sufficient. A horizontal north-south trough field typically gathers marginally more energy in a year than a horizontal east-west one. The north-south field, however, gathers a lot of energy in the summer and very little in the winter. Compared to a north-south field, the east-west field gathers more energy in the winter and less in the summer, offering a more.

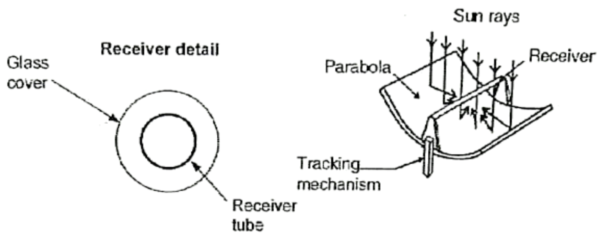


Fig 2.10 Parabolic trough collector

#### 2.8.2.2. Linear Fresnel reflector [36][38]

The linear mirror strip array used in LFR technology focuses light onto a stationary receiver fixed atop a linear tower. The LFR field can be thought of as a reflector that is a broken-up parabolic trough; however, unlike parabolic troughs, it does not have to have a parabolic shape, and it is possible to build large absorbers that do not require movement. In Fig. 2.11, an element of an LFR collector field is represented.

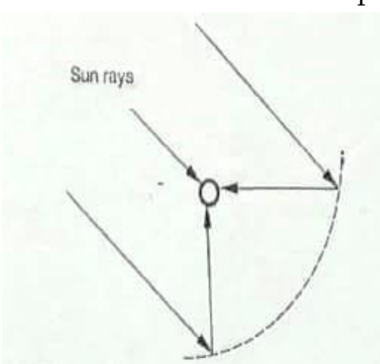


Fig. 2.11 Fresnel type parabolic trough collector

The main benefit of this kind of system is that it uses less expensive flat or elastically curved reflectors instead of parabolic glass reflectors. Giorgio Francia [25], a great solar pioneer who created linear and two-axis tracking Fresnel reflector systems at Genoa, was the first to apply this principle.

#### 2.8.2.3. Parabolic dish reflector (PDR)

A schematic representation of a parabolic dish reflector can be found in Figure 2.12. It functions as a point-focus collector, tracking the sun in two axes and focusing solar energy onto a receiver situated at the dish's focal point. For the beam to be reflected into the thermal receiver, the dish structure needs to follow the sun exactly. In order to track the collector in two axes, tracking mechanisms akin to those mentioned in the previous section are used in double. Systems with parabolic dishes are capable of reaching temperatures above 1500°C. Parabolic dishes are often referred to as distributed-receiver systems because, similar to parabolic troughs, the receivers are dispersed throughout a collector field.

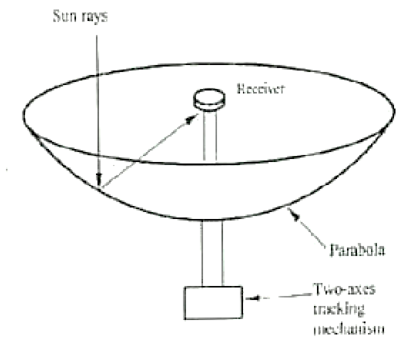


Fig. 2.12 Schematic of a parabolic dish collector.

#### 2.5.2.4. Heliostat field collector [36][37]

As illustrated in figure-2.13, a multitude of flat mirrors, or heliostats, mounted on altazimuth mounts can be utilized to reflect incident direct solar radiation onto a shared target for exceedingly high radiant energy inputs.

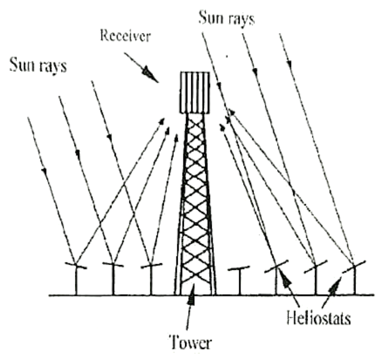


Fig. 2.13 Schematic of central receiver system.

This is referred to as the central receiver collector or heliostat field. A steam generator's cavity can be filled with a lot of thermal energy to create steam at a high temperature and pressure by using heliostats with slightly concave mirror segments. They take advantage of economies of scale because they are relatively large typically more than 10 MW.

### 2.6 Solar Air Heater

Solar air heater is device, which is used to increase the temperature of flowing air through the heater. Solar air heaters are used for moderate temperature applications like: Space heating. Crop drying. Timber seasoning Industrial applications Also the solar air heater is a vital component of a HD desalination system.

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