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A Review of Solar-Driven Desalination System Using Humidification-Dehumidification Process

Yogesh B Karhe[1], Mohd. Aasim Nazeer Ahmad[2]

[1]Mechanical Engineering Department, Dr. Babasaheb Ambedkar College of Engineering & Research, Nagpur, India

[2]Mechanical Engineering Department, Anjuman College of Engineering & Technology, Nagpur, India

ABSTRACT: *Desalination involves any process in which dissolved minerals are removed from saline or brackish water. This paper evaluates the characteristics for several layouts for the humidification dehumidification desalination process. Paper gives bird-eye view to Humidification-Dehumidification (HDH) process by comparing various authors' works. Paper provides necessary schematic figures, graphs between affecting operational and environmental parameters and tables wherever required. All vital components in the system were discussed in detail. In this paper, mathematical model, simulation and experimental work is reviewed .Further results, future scope & how to improve HDH process is mentioned in the paper. .*

Keywords: Humidification, Dehumidification, Desalination, Heat Exchanger, Double Glazing.

I. INTRODUCTION

There are two main challenges for the world in the future, shortage of energy, and shortage of fresh water, both of which play a crucial role in the overall economic development of any country [19].Conventional desalination technologies are usually large-scale, technology intensive systems most suitable for the energy rich and economically advanced regions of the world. They also cause environmental hazards because they are fossil-fuel driven and also because of the problem of brine disposal. In the following sections these conventional desalination technologies are introduced and their drawbacks are discussed. These heaters can amount to over 40% of the total cost of a humidification-dehumidification system and so the development of a cost effective and efficient solar collector is essential to the system's overall feasibility [1].

1.1 Conventional Desalination Technologies

1.1.1 Multi Stage Flash (MSF)

Pressurized seawater [2,8] flows through closed pipes where it exchanges heat, with vapour condensing in the upper sections of the flash chambers. Water is then heated to a certain initial high temperature, using burnt fuel or external steam, and this allows flashing along the lower part of the chambers, from chamber to chamber under reduced pressure conditions. Vapour generated is allowed to flow through a mist eliminator to meet the condensing tubes, where heat is transferred to the heating feed seawater. The condensate drips into collectors and is pumped out as the plant product. Exhausted brine, concentrated in salt, is pumped out and rejected to the sea. Part of the brine is recirculating with the feed in order to increase water recovery.

1.1.2 Multi-effect Distillation (MED)

Basically, the method [2, 17] can use low temperature, low-pressure steam as the main energy source. Steam from burnt coal or fuel can be used, as well as spent steam emerging at the outlet of a steam-operated power station. The primary steam is used to evaporate heated seawater and to generate more steam at a lower pressure, while the primary steam condensate is taken back to the generation chamber, or to the steam generator of the power station. The secondary steam generated goes into a second stage to condense while transferring the latent heat to low temperature seawater, flowing in falling film. The process is repeated as many times as the design permits, between the upper possible temperature and the lower possible coolingtemperature, which depends on seawater temperature. The condensate is accumulated stage wise as the product water. A vacuum pump takes the remaining vapour after the last condensation stage, to maintain the gradual pressure gradient inside the vessel.

1.1.3 Vapour Compression (VC)

The VC [2] operates mainly at a small scale, on small locations. The main mechanism is similar to MED except that it is based on compression of the vapour generated by evaporating water to a higher pressure, which allows reuse of the vapour for supplying heat for the evaporating process. Compression of the vapour may be carried out by using a mechanical compressor (the most common way), or by mixing with small amounts of high-pressure steam (Thermal Compression). Feed water is preheated against brine and the product leaving the system. Heat transfer usually takes place in the form of a double falling film, which is an effective heat transfer mechanism. The latent heat of the condensing vapour is used to make more vapours on the other side of the heat transfer surface, basically a "heat pump" process, so that the main need for energy is for elevating the pressure to provide the driving force by temperature difference. The process takes place usually from one to three stages, thus the operating temperature may be chosen for the best optimization of the process. No external heat is needed for the mechanical compressor, so basically the technique relies on the electric power supply. Part of the water circulates to increase the water recovery.

II. REVIEW OF HDH SYSTEMS

Y.J. Dai et al [3] has performed on water heated closed water open air (CWOA) system havingunit features like honeycomb wall humidifier, forced air circulation, the condenser is a fin-tube type. Main observations are large pressure losses can be avoided, condensation heat is recovered efficiently, other low-grade heat resources such as waste heat, gas/oil/coal burning, etc, can also be efficiently utilized. Guofeng Yuan et.al [4] work on water heated CWOA system having unit features of honeycomb paper used in humidifier,forced convention for the air circulation, condenser is fin tube type. Main observations are performance strongly dependent on temperature of inlet salt water to the humidifier, the mass flow rate of salt water, and the mass flow rate of the process air, the authors report that there is an optimal air velocity for a given top temperature of water. Cemil Yamali et al. [5] has performed on water heated CWOA having a single stage double-pass flat-plate solar collector heats the water, a pad humidifier is used and the dehumidifier used is a finned tube heat exchanger also a tubular solar water heater was used for some cases. It was observed that the plant produced 4 kg/day maximum, increase in air flow rate had no effect on performance, an increase in mass flow rate of water increased the productivity.

Anil Kr Tiwari [6] was worked by using double-pass flat plate solar air heater with two glass covers, mathematical modeling & observed that the productivity of the proposed system increases up to 10% & air mass flow rate should have optimum value. Orfi et al [7] used combined air heated open or closed one & water heated solar heater, the condenser contains two rows of long cylinders made of copper in which the feed water flows. Longitudinal fins are soldered to outer cylinder. Both theoretical & experimental study on the system.The theoretical results show that there exists an optimum mass flow rate corresponding to a maximum fresh water product. Nafey et al. [9] uses system which is unique in that it uses a dual heating scheme with separate heaters for both air and water. Humidifier is a packed bed type with canvas as the packing material. Air cooled dehumidifier is used and hence there is no latent heat recovery in this system. The authors reported a maximum production of 1.2 L/h and about 9 L/day. Higher air mass flow gave less productivity because increasing air flow reduced the inlet temperature to humidifier. Chafik et al [12] work with solar collectors (four-fold-web-plate, or FFWP, design) of 2.08 m2 area heat air to 50–80C, multi-stage system, pad humidifier with corrugated cellulose material, 3 separate heat recovery stages & forced circulation of air. The solar air heaters constitute 40% of the total cost. Also he observed that the system can be further improved by minimizing the pressure drop through the evaporator and the dehumidifiers.

2.1 Review of Solar Air Heater

Various types of solar air heaters according to construction & there features are discussed one by one.
Air flow over the absorber plate where the absorber decreases losses from the top of the absorber plate and eliminates conduction resistance through the plate. Roughened absorber plate which improves convection heat transfer into the air. A rough configuration also increases pressure drop, but only marginally as compared with a smooth plate. Multiple passes of air through the collector improves heat gain by increasing contact with the absorber and makes the absorber run cooler, decreasing losse. Multiple glazing layers, it reduce heat loss by infrared radiation and trap an insulating air layer between the glazings. Glass and metal construction, it provides better heat transfer characteristics and better durability. All the best performing collectors used glass and metal construction, as polymer alternatives, especially for glazings, suffer from low durability, although initially providing optical properties comparable to glass. Packing materials in the air stream improve heat transfer by

mixing the air and providing more surface area to absorb radiation. Packing also provides sensible heat storage but comes at the cost of high pressure drop.

Guofeng Yuan [4] works on the72 pieces of solar air heaters with a total surface area of approximately 100 m2. These collectors use evacuated tubes with inner pipes, which could provide higher air temperature than panel solar collectors. 72 pieces is divided into 2 subgroups containing 36 pieces/group & they are connected in parallel. Then each group is divided again into 3 sub-groups (12 pieces/sub-group), with pieces in every single sub-group connected in parallel, and sub-groups connected in parallel as to each other in order to ensure the uniformity of air distribution and reduce air flow rate in the air Trunk. Author [5,6,11] used double-pass flat plate solar air heater (100*50*10 cm3).It consists of two glass covers having a thickness of 3 mm matt black painted 1 mm thick copper absorber plate The container of the solar air heater that was made of iron sheets of 2 mm thickness was fabricated by welding. The solar air heater was positioned at a tilt angle of 30° facing south Productivity increases about 15% by double-pass solar air heater. A tubeless flat plate solar collector with a single glass cover is used for air heating. The Heater effective area is 0.5 m• 1 m, and the absorber plate is made of copper with a thickness of 0.5 mm. The air gap between the absorber and the glass cover is 0.01 m [7-10] which could provide higher air temperature than panel solar collectors.

Solar air heater efficiency: It is defined by Eq. 1. [1] $\eta = m\, c_p\, (T_{out} - T_{in})/ I_T$, where m-mass flow rate of air through the collector in kg/s, c_p specific heat capacity of air at constant pressure, J /kg K, T_{out} outlet temperature of air, K, T_{in}- inlet temperature of air, K, I_T solar irradiation, W/m2

2.2 Review of Humidifier

Kreith [24] used spray tower which is cylindrical vessel in construction water is sprayed at the top of the vessel and air stream flowing upward. The diameter-to-length ratio is a very important parameter in spray tower design. Design of spray towers requires knowledge of heat and mass transfer coefficients as well as the contact surface area of the water droplets. Minimal pressure drop on the gas side considerable pressure drop on the water side due to the spray nozzles.High capacity but low efficiency, the low efficiency is as a result of the low water hold-up due to the loose packing flow. El-Agouz and Abugderah [25] studied the single Bubble column exactly opposite in principle to the spray tower is the bubble column. A vessel is filled with water and air bubbles are ejected from several orifices located at the bottom of the vessel. The diffusion of water into the air bubbles depends on many parameters such as bubble diameter, bubble velocity, gas hold-up (the ratio of air bubbles-to-water volume), water and air temperatures as well as the heat and mass transfer coefficients geometrical factors such as the orifice diameter, number of orifices, water head height and column diameter influence the performance.Muller-Holst et al. [26] was worked with Wetted-wall towers in which Pipes are arranged in vertical manner water is loaded into the top of the tower. A weir distributes the flow of water around the inner perimeter of the tube that wets the inner surface of the tube down its length. Such devices have been used for theoretical studies of mass transfer. A thin film of water is formed running downward inside a vertical pipe, with air flowing either co-currently or counter currently. Evaporators J. Orfi [7] it is horizontal and has a rectangular cross section is constructed with wood. The fiber glass is used for insulation. Five parallel plates made with wood and covered with textile (cotton) are fixed in the evaporator. Tubes are placed on the vertical plates. The feed water and the air are counter current. It improves the heat and mass exchange. The horizontal surface of the evaporator is covered by the hot water. The vertical plates are wetted by capillarity and finally the water is sprayed by means of tubes with small holes set in them.

2.3 Review of Dehumidifier

The process air passes through the condenser cooled by cold seawater where water vapor condenses and turns into fresh water. The condenser of a fin-tube type one of cross sectional area 1.5*1.5 m was used by Y.J. Dia[3]. Cold seawater flows in the tube channel and fresh water is produced on condensation surface in the condenser at the same time. In similar study G. Yuan[4] used two parallel fin tube heat exchanger one above other to strengthen the cooling capacity. Special feature is that humidifier and dehumidifier is composed as single equipment having no physical isolation between them. J. Orfi [7] used. The condenser consists of a chamber with a rectangular cross section. It contains two rows of long cylinders made of copper in which the feed water flows. Longitudinal fins were soldered to the outer surface of the cylinders. The condenser is characterized by an exchange surface, 1.5 m 2 and 28 m as total length. K. Bouroni [8] used horizontal tube bundle through which the brine coolant passes in counter-current flow to the fresh water stream surrounding the tube bundle is the most used configuration.

Cemil Yamali [5] worked with three-air cooler heat exchangers manufactured with copper tubes and corrugated aluminum fins were used as a dehumidifier. They were connected to each other with copper tubes in series (exit of one cooler was connected to the inlet of the other cooler). The surface area of each condenser is 3.5 m2 (i.e., the total surface area of the dehumidifier is 10.5 m2). In order to prevent air leakage and heat gain, dehumidifier heat exchanger was placed on an insulated metal box. It was constructed of 2 mm thick galvanized steel by welding. Its dimensions are 40 cm × 47 cm × 34 cm. Chafik [12] used seawater as a coolant wherein the water is heated by the humid air before it is pumped to the humidifiers. Three heat exchangers were used in three different condensation stages. A additional heat exchanger is added at the intake of sea water (low temperature level) for further dehumidification of air. The heat exchangers (dehumidifiers) are finned-tube type air coolers. They developed a theoretical model. The standard method as developed by McQuiston [14] considers finned-tube multi-row multi-column compact heat exchangers and predicts heat and mass transfer rates using Colburn j-factors along with flow rate, dry- and wet-bulb temperatures, fin spacing and other dimensions. The air side heat-transfer coefficient is based on log-mean temperature difference for the dry surface whereas under the condensing conditions, the moist air enthalpy difference is used as a driving potential.

III. CONCLUSIONS

The HD process presents a very interesting solution for small units (hotels, rural regions, light industry, etc.), especially when new materials are used. The process is very convenient in cases where heat is available at low temperature at an attractive cost (cogeneration, solar energy, geothermal energy, etc.)[8]. From the present review it is found that among all HDH systems, the multi-effect CAOW water-heated system is the most energy efficient[14]. A collector with a double glazing, a highly roughened absorber, and a carbon black coated absorber, results in a collector efficiency of 58% [1]. It is necessary to obtain the best design and operating conditions that give the minimum product cost.

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