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Review of Dehumidifier with Association to Solar Circular Collector for Close Water Open Air System (CWOA) Humidification & Dehumidification Process

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Abstract— *Coastal area where clean drinking water availability is measured problem, which insist to innovate cheep, decentralized small-scale water production.The geographical conditions of vadodara (22.00N, 72.10E),and kachh,Gujarat are best suitable for humidification-dehumidification (HDH) technique based on closed-water, open-air cycle where air heated system is used. There are different types of heat exchangers available as dehumidifiers for HDH applications vary but they have required strength to withstand corrosive nature of seawater, there for frames, collecting plates, fins are made of aluminum. In addition, special attention was exercised to avoid leakage of distillate water. Dehumidifiers is heat exchanger in which heat exchange is takes places between two fluids i.e. hot and cold that are at different temperatures. The heat exchange in the heat exchanger may be in the form of latent heat or sensible heat or combination of both. The HDH concept are also reviewed and compared. Further, novel proposals for improvement of the HDH cycle are outlined. It is notice that HDH technology has great promise to produced fresh water using circular solar collector, although additional research and development is needed for improving system efficiency and reducing capital cost.*

Keywords— Humidification, Dehumidification, Desalination, Decentralized Water Production, Solar power, Small-Scale Water Production.

I. INTRODUCTION

Many process are used to bringing down total dissolved solids of 35000ppm to an acceptable level of 500ppm. More power required to run such plants can be obtained from renewable sources or non-renewable sources of energy Desalination plants driven by renewable energy sources are generally economically competitive compared to the classical processes powered by fossil energy. Therefore distillation with solar energy remains one of the most favorable processes. For small-capacity water desalting for remote regions, where there is substantial solar radiation, lack of skilled personnel or erection and maintenance facilities. Combining the principle of humidification–dehumidification (HD) with solar desalination results in an increase in the overall efficiency of the desalination plant and therefore appears to be the best method of water desalination with solar energy. Al-Hallaj and Selman have concluded that a better understanding of this method of desalination is highly desirable. performance of a unit can be optimize by Simulation verification and design of varying the three major components (humidifier, condenser and collector area) of the unit is perhaps such first optimization till date that could be the critical step in the commercialization of solar desalination based on humidification–dehumidification principle.The main important attraction of the air humidification–dehumidification technique is its conceptual less complex with respect to other desalination processes. This can be described by bringing warm unsaturated air into contact with warm water under specified conditions in order to reach certain desired air humidity. This step, is then, followed by stripping out the water vapor in the humidified air by passing it through a dehumidifier . The vapor carrying capability of air increases with temperature; 1 kg of dry air can carry 0.5 kg of water vapor and about 2803 kJ when its temperature increases from 30 to 80°C. The HD process should essentially include a heating device for both air and water and a humidifying apparatus in order to bring them into contact. The dehumidification technique could be either a direct spray of fresh water on humidified air or condensation of the water content in the humidified air by a heat exchanger.

II. HISTORICAL BACKGROUND OF HD TECHNIQUE

The literature review in this work was based mostly on works of Al-Hallaj and Selman, which represent, to our knowledge, the most comprehensive state-of-the-art project-study helpful for further development of HD

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techniques. The solar HD technique has attracted many researchers since early periods. In 1967,Garg reported a study with the aim of developing the HD technique for water desalination in arid zones of India. A 3.4-L/d capacity experimental unit was fabricated having a packed tower with packing height of 30 cm with Raschig rings as packing material. The humidification unit was coupled with a surface condenser (dehumidifier). In 1972, Mehta improved this technique by using an air-recycling system driving the air from the outlet-dehumidifier to the humidifier-inlet. The main advantages of this air-recycling system are a 20% reduction or more of the volume of the packed-column humidifier and higher stability in the operation mode of the plant. In 1970, Grune introduced the multiple effect- humidity (MEH) process, which he had been investigating since early 1960s. In reality, the term “multiple effect” used there did not refer to the number of constructed stages, but to the ratio of heat input to heat utilized for distillate production (GOR > 1). The University of Arizona, based on a pilot plant work performed from 1956 to 1963, initiated construction of an experimental pilot plant working on the principle of solar energy MEH. Further work was initiated in 1964 by the University of Arizona in cooperation with the University of Sonora (Mexico) whereby a larger pilot-scale solar desalting plant at Puerto Penasco, Sonora, Mexico, were constructed. Kheder performed a techno-economic investigation of an air HD desalination process. The results showed that 76% of the energy consumed in the humidifier was recovered by condensation. Their cost calculation showed that HD process has a significant potential as an alternative for small capacity desalination plants below 10 m³/d. During the period 1990 to 1996, Farid and coworkers had built three MEH desalination units in Iraq (Basra), Jordan and Malaysia. The unit constructed in Iraq was operated with forced air circulation and produced 12 L/m²d; while the unit constructed in Jordan was operated with both forced and natural draft air circulation. Based on the experience of operating these units, a third unit operated with natural draft air circulation was constructed in Malaysia. These units were built in order to develop a computer simulation program, which could be used to predict the performance of the HD units operating on natural or forced draft air circulation. The University of Munich and the Bavarian Center of Applied Energy Research installed and tested a MEH natural-convection unit in the Canary Islands in Spain during the period 1992–1997. The performance of the unit was improved over the years and an average daily production of 100 L out of 8.5m of collector area (11.8 L/m²d) was obtained by the system without thermal storage. 2Müller-Holst studied and installed a MEH unit without thermal storage in the island of Fuerteventura with a GOR ranging between 3 and 4.5. But this unit did not reach a GOR of 8 obtained in the laboratory at ZAE Bayern at steady-state conditions. In a related study, Ulber investigated and installed in 1997 in Sfax (Tunisia) a unit with a conventional heat storage tank (2 m³) and heat exchange between the collector circuit (38 m²) and the distillation circuit. This enabled continuous (24 h/d) distillate production. In 1991, Graef studied a desalination process based on a solar multiple condensation– evaporation cycle (SME). Two types of desalination units SME 3.6 (50 L/d) and SME 200 had been in operation in Sfax (Tunisia) since 1991 Experimental study on these units performed by Ben Bacha had deliberated a condensate production of 4 L/m²d with a collector efficiency of 46% (theoretical production: 14.3 L). Delyannis and Belessiotis built at Kuwait University a unit based on open-air/closed-water cycle of 9.8-m³/d capacities. A salt gradient solar pond of 1700 m2 (5.8 L/m²) provided the unit with thermal energy. Khalil noted that this method of desalination might be economical only if the produced fresh water was considered as an air-conditioning by-product. Dai and Zhang also built an MEH unit operated in an open-air/ closed-water cycle of 100 L/h fresh water with maximum production capacity (6.2 L/m²d). Another MEH unit based on open-air/closed-water cycle and referred to as “Dew vapouration” was built at Arizona State University, for the production of 45.4 kg/d of condensate, with GOR values in excess of 7.5.

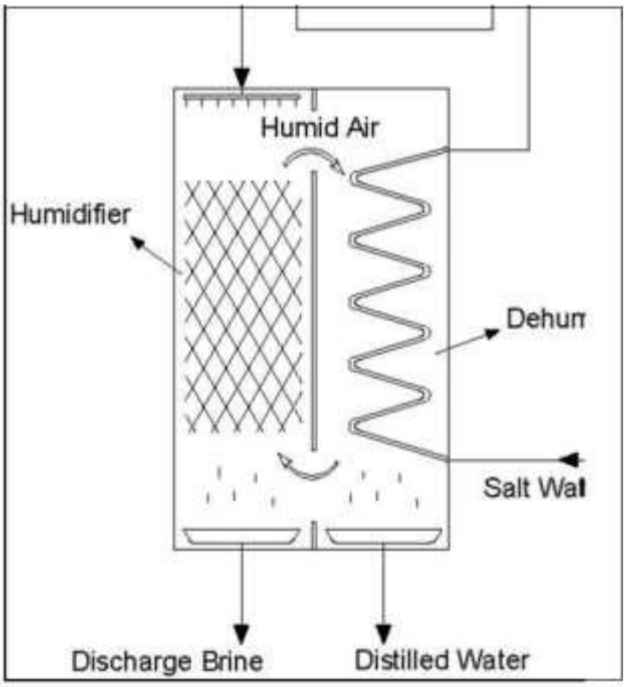

Fig.1: Schamatic Diagram of Dehumidifier

III. HEAT EXCHANGERS USED AS DEHUMIDIFIERS

For example, flat-plate heat exchangers were used by Müller-Holst et al. [17]. Others used finned tube heat exchangers ([16], [18] & [50]). A long tube with longitudinal fins was used in one study [59], while a stack of plates with copper tubes mounted on them in another study ([60] & [61]) used a horizontal falling film-type condenser. Direct contact heat exchangers were also used as a condenser in some other studies [62] in combination with a shell- and-tube heat exchanger to provide enhanced condensation and improved heat recovery for the cycle.A flat plate heat exchanger made of double webbed slabs of propylene was used by Muller-Holst [17] in his HDH system. The distillate runs down the plates trickling into the collecting basin. Heat recovery is achieved by transferring heat to the cold sea water flowing inside the flat plate heat exchanger. The temperature of sea water in the condenser increases from 40o to 75oC. In a similar study, Chafik ([16] & [18]) 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. An additional heat exchanger is added at the intake of sea water (low temperature level) for further dehumidification of air. The heat exchangers (or dehumidifiers) are finned tube type air coolers. They developed a theoretical model by using TRNSYS to calculate heat transfer coefficients from both the hot- and cold-sides of the heat exchanger from which the system operating conditions were set. It is important to note that to withstand corrosive nature of seawater; stainless steel is used for frames, collecting plates, while the fins are made of aluminum. In addition, special attention was exercised to avoid leakage of distillate water.Different designs of condensers in a HDH cycle were used by Farid et al. ([59] & [63]). In a pilot plant built in Malaysia, the dehumidifier was made of a long copper galvanized steel tube (3 m length, 170 mm diameter) with 10 longitudinal fins of 50 mm height on the outer tube surface and 9 fins on the inner side. In another location, they used a simplified stack of flat condenser made of 2 x 1 m2 galvanized steel plates with

long copper tubes mounted on each side of the plate to provide a large surface area. The condenser size was made large, particularly to overcome the small heat transfer coefficients both on the air- and water-sides due to relatively low air velocity, as well as low water flow rates.In another design, the dehumidifier was made of 27 m long copper pipe having a 10 mm OD, mechanically bent to form a 4 m long helical coil fixed in the PVC pipe. The preheated feed water was further heated in a flat plate collector. The hot water leaving the collector was uniformly distributed over a wooden shaving packing in a 2 m long humidifier. It is important to note that the condenser or dehumidifier was made of hard PVC pipes connected to form a loop with the blower fixed at the bottom. The condenser was made of a copper pipe mechanically bent to form a helical coil fixed in the PVC pipe.Two types of condensers were reported in another study by [60]. These were constructed from galvanized steel plates for both the bench and pilot units. In the pilot unit, a copper tube having 11 mm OD and 18 m long was welded to the galvanized plate in a helical shape. The tube outside diameter and length in the bench unit were 8 mm and 3 m, respectively. Either one or two condensers, connected in series, were fixed vertically in one of the ducts for both the units. In one unit, the condenser was simply a 3 m long cylinder having a diameter of 170 mm and made of galvanized steel plates. Ten longitudinal fins were soldered to the outer surface of the cylinder and nine similar were soldered to the inner surface. The height of inside and outside fins was 50 mm. The thickness of the plate that was used to make the cylinder and the fins was 1.0 mm. A copper tube having 9.5 mm inside diameter was soldered to the surface of the cylinder. The condenser was fixed vertically in the 316 mm diameter PVC pipe which is connected to the humidifier section by two short horizontal pipes. Bourouni et al. [61] used a condenser made of polypropylene which was designed to work at low temperatures (70-90°C) for a HDH system. It is similar to a horizontal falling film-type condenser. At the top of the dehumidifier, the hot humid air is forced down where the distilled water is recovered. It is important to note that heat recovery in an HDH system requires a larger heat transfer area for improving the overall system performance. For this reason, 2000 m of tubes are used in the evaporator, while 3000 m of tubes in the condenser. The system Orfi et al. [52] used had two solar heaters, one for heating water and the other for heating air. The condenser, that uses seawater for cooling, 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 heat-transfer surface area of 1.5 m2 having 28 m as a total length of the coil. Packed bed direct contact heat exchangers were used in a few researchers ([52], [64] & [65]), because the film condensation heat transfer is tremendously degraded in the presence of non-condensable gas. An additional shell and tube heat exchanger is used to cool the desalinated water from which a portion is re-circulated and sprayed in the condenser.Threlkeld [66] explains the governing equations for the dehumidifier in differential form. Also, design correlations for both friction factor and heat transfer coefficients that can be used for dehumidifiers are summarized by Pacheco-Vega et al. [67].The standard method as developed by McQuiston ([68] & [69]) 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

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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.Pacheco-Vega et al. [67] used neural network techniques and the experimental data collated by McQuiston, to create a trained network that predicted the exchanger's heat rate directly. Remarkably accurate results were obtained as compared with the method of using correlations of heat and mass transfer coefficient and Colburn j factors. They focused on the exchanger heat rate since it is the value ultimately desired by users. A significant improvement in the accuracy of predictions compared to the conventional jfactor approach was demonstrated, e.g., 56.9% less error for drop wise condensation and 58.6 % less error for film wise condensation have been reported

IV. CLASSIFICATION OF DEHUMIDIFIER

Dehumidifiers is heat exchanger in which heat exchange is takes places between two fluids i.e. hot and cold that are at different temperatures. The heat exchange in the heat exchanger may be in the form of latent heat or sensible heat or combination of both. Solid wall may or may not separate two fluids.

Dehumidifier Classified On The Basis Of The Following.

4.1Nature of heat exchange process:

Direct contact (open): Heat exchange takes place through direct mixing of hot and cold fluids. Examples are cooling towers, jet condensers and direct contact feed heaters.

Indirect contact (surface): Regenerators- In this hot and cold fluids are flow alternately through same space alternately with no or little mixing between the streams. Examples are the regenerators are used in most of the gas to gas heat exchangers such as internal combustion engine and gas turbines. Other applications include open hearth and glass melting furnaces and air heaters of blast furnaces.

Recuperates- This is the most common type of heat exchanger in which two fluids are separated by surface between them. Examples are oil coolers, intercoolers, economizer super heaters, condensers, radiators and evaporator.

4.2 Relative Directions of Fluid Motions:

Parallel flow-In this hot and cold fluids flow in the same directions. Examples are water heaters, oil coolers etc.

Counter flow- This is the most favorable device in which hot and cold fluid flows in opposite directions. Cross flow-Two fluids are flow in normal to each other for example automobile radiators

4.3Design and Construction Features:

It includes concentric tube, shell and tubes; multiple shells and tube passes and compact heat exchanger.

4.4 Physical State of the Fluids:

In this category Condensers and Evaporators are present according to state of fluid.

V. TYPES OF DEHUMIDIFIER

There are following type of Dehumidifier(a).Air cooled (b)Water cooled (c).Evaporative type dehumidifier

5.1.1 AIR COOLED: - In this type of dehumidifier heat is removed by air using either natural or forced circulation. The dehumidifier is made up of steel, copper or aluminum tubing provided with fins to improve airside heat transfer. The refrigerant flows inside the tubes and the air outside.

They are used for small capacity machines, such as refrigerators and small water and small water coolers, which use vertical wire and tube or plate and tube construction with natural circulation. These are seldom made in sizes over 5TR because of high head pressure, excessive power consumption and objectionable fan noise.

5.1.2 Water-cooled: - In this type, the arrangement can either be namely, shell and tube, shell and coil or double tube.

52.1 Shell and tube: - in this the water flowing through passes inside the tube and the refrigerant condensing in the shell is most commonly used condenser. This type of dehumidifier also serves the purpose of a receiver, specially for pumping down the refrigerant, because there is enough in the shell and the bottom part serves the purpose of a sub-cooler as the condensed as the condensing liquid comes in contact with the entering water at a lower temperature.

5.2.2 Shell and coil: - it consists of an electrically welded closed shell containing a water coil sometimes of finned tubing.

5.2.3 Double tube: - the refrigerant condenses in the outer tube and the water flows through the inner tube in opposite direction.

Water cooled condensers are invariably used in conjunction with cooling towers, spray ponds etc. heated water from the condenser is led to the cooling tower where it is cooled by self-evaporation into the stream of air. After cooling, the water is pumped back to the condenser.

5.3 Evaporative dehumidifier The refrigerant first rejects its heat to the water and then water rejects its heat to the air, mainly in the form of evaporated water. Air leaves with high humidity as in a cooling tower. Thus an evaporative condenser combines the function of a condenser and cooling tower. Evaporative condensers are generally used on large ammonia plants as they are found to be cheaper. Such condensers require a larger amount of refrigerant charge due to longer length of the refrigerant piping. But in case of ammonia systems this is immaterial since the refrigerant is quite cheap.

VI. ENERGY AND MASS BALANCES EQUATIONS

Energy and mass balances are applied to a segment of height Δy as shown in Fig

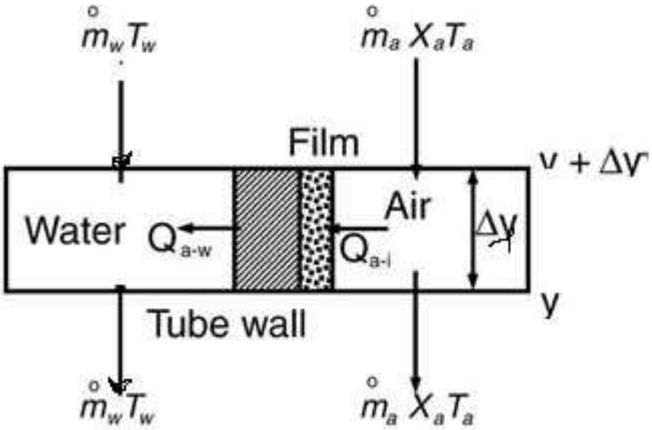

Fig.2: An element of the dehumidifier

$$\mathbf{M_{cw}Cp_{cw}(T_{cwo} - T_{cwi}) = M_a(H_o - H_c)} \quad (1)$$
$$\mathbf{M_{cw}Cp_{cw}(T_{cwo} - T_{cwi}) = U_cA_cLMTD_c} \quad (2)$$

The logarithmic mean

$$\mathbf{LMTDc} = \frac{\mathbf{(Tac - Tcwo\ )(\ Tac - \ Tcwi)}}{\mathbf{ln}\left(\frac{\mathbf{(Tao - Tcwo)}}{\mathbf{(Tac - Tcwi)}}\right)}$$

The production of distilled water is given by the following balance equation

$$\mathbf{Md = Ma(Wo - Wc)}$$

Dehumidifier effectiveness η

$$\boldsymbol{\eta} = \frac{\mathbf{T_3 - T_4}}{\mathbf{T_3 - T_{amb}}}$$

VII. THE GOVERNING EQUATIONS OF THE DEHUMIDIFICATION PROCESS

The following equations were derived to describe the heat and mass balances in the dehumidifier

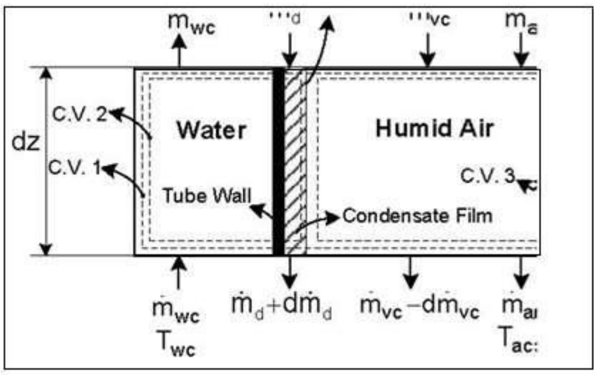

Fig. 3: Element of dehumidifier

As shown in Fig. 3 it can be written for control volume 1

$$\mathbf{C.V.1}: \qquad \mathbf{dm_d = dm_{vc} = m_{ac}d\omega_c}$$

The following heat balance is confirmed for the C.V.2 (water side).

$$\mathbf{C\ C.V.2} \qquad \frac{\mathbf{dT_{wc}}}{\mathbf{dz}} = \frac{\mathbf{h_{wc}\alpha_{Hc(T_{wi}-T_{wc})}}}{\mathbf{m_{wc}c_{wc}}}$$

For C.V.3 (air side) two equations can be written. The first is a mass balance and the second is a heat balance

$$\text{C C.V. 3} \qquad \frac{d\omega_c}{dz} = \frac{k_{ac}\alpha_{Mc(\omega_c-\omega_{ic})}}{m_{ac}}$$

$$\frac{dT_{ac}}{dz} = \frac{h_{ac}\alpha_{Hc(T_{ac}-T_{ic})}}{m_{ac}(C_{ac}+\omega_c C_{vc})}$$

Finally heat balance for interface is as follows:

$$\mathbf{h_{wc}\alpha_{Hc(T_{wi}-T_{wc})}} = h_{ac}\alpha_{Hc(T_{ac}-T_{ic})} + L_{ve}k_{ac}\alpha_{Mc(\omega_c-\omega_{ic})}$$

The interface is assumed to be a film of saturated air. Therefore Tie and ωie are dependent variables. Stocker and Jones [10] introduced an experimental relation for evaluation of absolute humidity according to temperature which has a suitable accuracy:

$$\boldsymbol{\omega_{ie}} = f_{exp(T_{ie})} = 2.19 \times 10^{-6}\mathrm{T_{ie}^3} - 1.85 \times 10^{-2}\mathrm{T_{ie}^2} - 7.06 \times 10^{-3}\mathrm{T_{ie}^0} - 0.077$$

VIII. CONCLUSION

It is important to note that to withstand corrosive nature of seawater; stainless steel is used for frames, collecting plates, while the fins are made of aluminum. In addition, special attention was exercised to avoid leakage of distillate water. The condenser size was made large, particularly to overcome the small heat transfer coefficients both on the air- and water-sides due to relatively low air velocity, as well as low water flow rates.

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