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A Review of Circular Solar Collector for Close- Water, Open-air (CWOA) air Heated Humidification and Dehumidification Process

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Abstract: **The efficiency of a solar collector is a key factor for the performance of thermal facilities. As the weather conditions vary continuously during the day, the instant collector efficiency depends not only on the components employed in its construction but also on the actual environmental conditions. As per the previous works by different authors, it has been found that, the open air/closed water HD desalination system is suitable at Gujarat location which has low relative humidity of air. In open air/closed water system increasing mass flow rate increase the productivity. In flat plate air heaters cost incurred due to insulation cladding are more so the air heaters with less amount of insulation are required to develop.**

1. INTRODUCTION

Drinking water of acceptable quality has become a scare commodity. In India, especially in Gujarat long coastal line from Kutch to Selvassa via khumbhat, large sea water is available. Valsad, Surat, north Gujarat where underground water having high salt concentration which is not suitable for human use. Nandesari, Bharuch, vapi and ankleshwar, suffering pollute water due to industrial growth. Therefore, desalination has become an important technique to provide fresh water.

Water desalination using Humidification-Dehumidification technique present several advantages, such as flexibility in capacity, easy installation, moderate operation cost, simplicity and decentralized application.

Energy use has become a critical concern in the last decade. Moreover environmental issues of conventional energy resources, such as climate change and global warming, Due to rapid growth in conventional fuel price and environmental constraint, traditional energy supply shifted to renewable energy sources. Among all renewable energy sources, solar power attracted more attention because solar energy is abundance, free and clean, which doesn't make any noise or any kind of pollution to environment. The absolute value and the intensity of solar radiation over a year depend strongly on latitude. Tropic of Capricorn passing through Gujarat, the average monthly isolation is evenly distributed through the year.

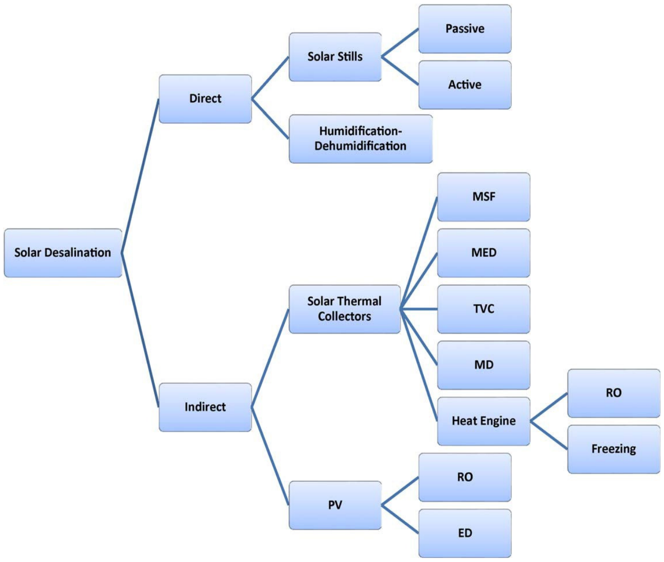

Fig. 1. Classification of Solar distillation [44]

The daily average solar energy incident over India varies from 4 to 7 kWh/m2 with about 1500–2000 sunshine hours per year, depending upon location. The global solar insulation receive in Gujarat is more than 5.25 kwh/m2/day.

1.1. Humidification–Dehumidification Process

Bourouni has reviewed the principle of functioning of the 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 carry0.5 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 vapor 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 vapor in the air. Generally, 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. The HD technique is especially suited for seawater desalination when the demand for water is decentralized.

1.2 Thermodynamic Process Involved in HD Technique

Heating and Humidifying of air can be described using the psychometric chart, An airflow with initial temperature and initial humidity as indicated in the item 1, i.e. 25ºC and 10g of water per kg of dry air, can be heated up to 80ºC (item 2) and humidified by adiabatic injection of water to increase its humidity up to 30g/kg of air accompanied by decrease in the temperature.

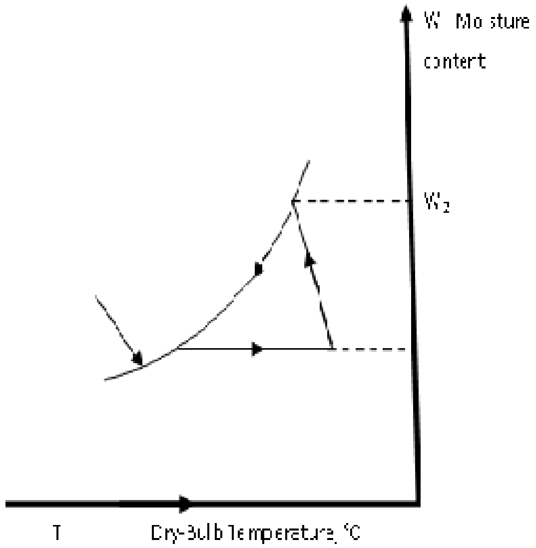

Fig. 2. Thermodynamic Processes Involved In HD Technique [43]

1.3 Closed-air open-water (CAOW) water-heated systems

A typical CAOW system is shown in Fig.4. The humidifier is irrigated with hot water and the air stream is heated and humidified using the energy from the hot water stream. This process on the psychometric chart is represented by the line 1–2 (Fig. 4).The humidified air is then fed to the dehumidifier and is cooled in a compact heat exchanger using seawater as the coolant. The seawater gets pre-heated in the process and is further heated in a solar collector (Qin indicated in Fig.4 is the heat absorbed in the solar collector by the seawater as used in the calculation of GOR) before it irrigates the humidifier. The dehumidified air stream from the dehumidifier is then circulated back to the humidifier. This process on the psychometric chart is represented by the line 2–1

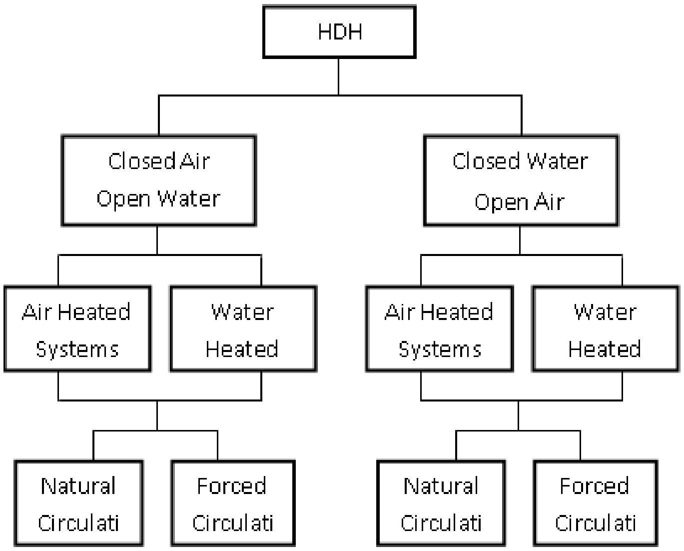

Fig. 3 Classification of typical HDH processes [43]

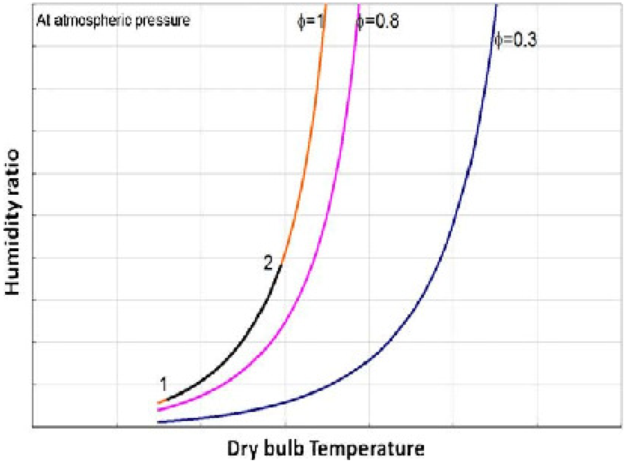

Fig. 4. Closed-air open-water (CAOW) water-heated systems [43]

1.4 Closed-water open-air (CWOA) water-heated

A typical CWOA system is shown in Fig. 5 In this system the air is heated and humidified in the humidifier using the hot water from the solar collector then air is dehumidified using outlet water from the humidifier. The water, after being pre-heated in the dehumidifier, enters the solar collector, thus working in a closed loop. The dehumidified air is released to ambient. The humidification process is shown in the psychometric chart (Fig. By line 1–2. Air entering at ambient conditions is saturated to a point 2 (in the humidifier) and then the saturated air follows a line 2–3 (in the dehumidifier). The air is dehumidified along the saturation line.

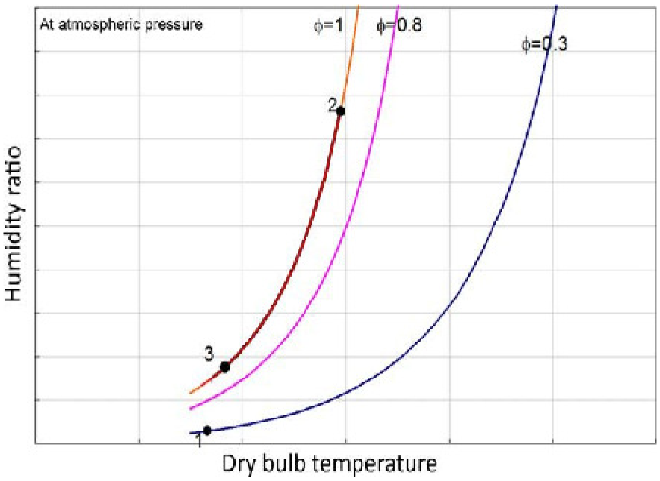

Fig. 5 Closed-water open-air (CWOA) water-heated [43]

1.5 Closed-air open-water (CAOW) air-heated systems

Another class of HDH systems which has attracted much interest is the air-heated system Fig.6 is a schematic diagram of a single stage system. The air is heated in a solar collector to a temperature of 80–90. C and sent to a humidifier. This heating process is represented by the constant humidity line 1–2 in the psychometric chart (Fig.6), in the humidifier; the air is cooled and saturated. This process is represented by the line 2–3. It is then dehumidified and cooled in the process 3–1 represented on the saturation line. A major disadvantage of this cycle is that the absolute humidity of air that can be achieved at these temperatures is very low (<6% by weight). This impedes the water productivity of the cycle.

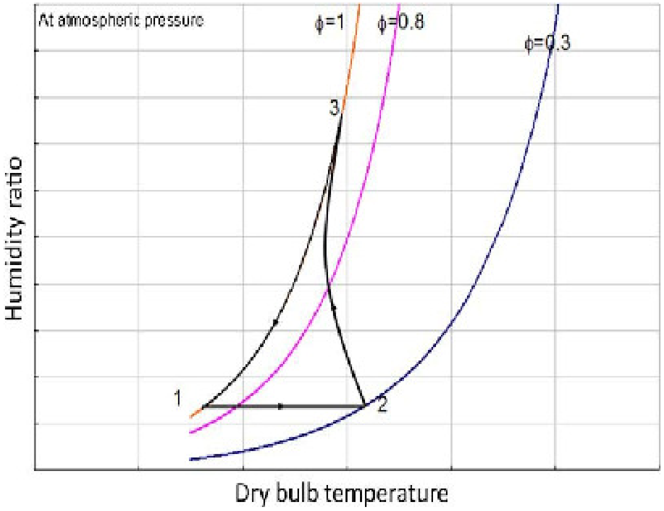

Fig. 6 Closed-air open-water (CAOW) air-heated systems [43]

1.6 Air-heated CWOA HDH process

The air after getting heated in the solar collector (line 1–2) Air humidified in the evaporator (line 2–3) it is dehumanized in the condenser

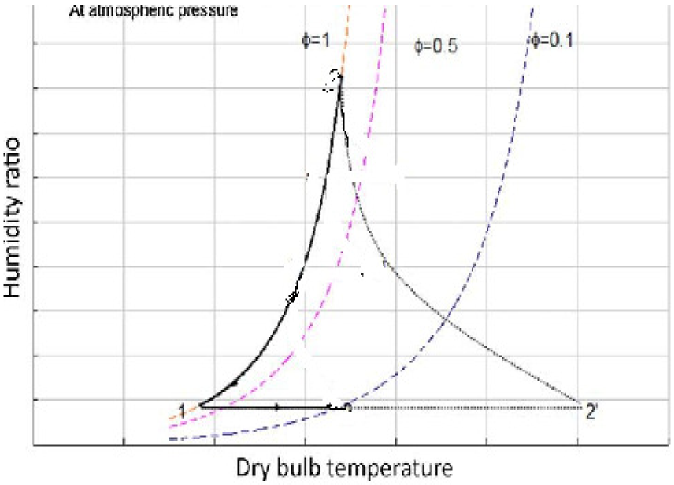

Fig. 7 Air-heated CWOA HDH process [43]

Desalination research and developments of new technologies for small capacity plants is strongly hampered by the rapid progress of the reverse osmosis process (RO). Also another important factor is the use of the ever reliable and large scale multi-stage flashing desalination plants (MSF). Also, use of water distribution networks is common even for remote and small population areas. This makes development and use of new technologies highly challenging because of difficulties another important factor is the use of the ever reliable and large scale multi-stage flashing desalination plants (MSF). Also, use of water distribution networks is common even for remote and small population areas. This makes development and use of new technologies highly challenging because of difficulties in applying and accepting new technologies and lack of field experience. Irrespective of these facts, the capital for MSF plants together with an intensive water distribution system is very large. Also, the RO process requires high level of technology for membrane synthesis and module preparation. In addition, feed pretreatment for the RO process is necessary and intensive in most cases.

2. LITERATURE REVIEW

Air heating collectors have been occasionally used since World War II, mostly for low temperature space heating applications. 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. The 1959 Colorado Solar House [5] used a glass and metal collector with many glazing’s staggered on top of each other, and achieved 30% efficiency.

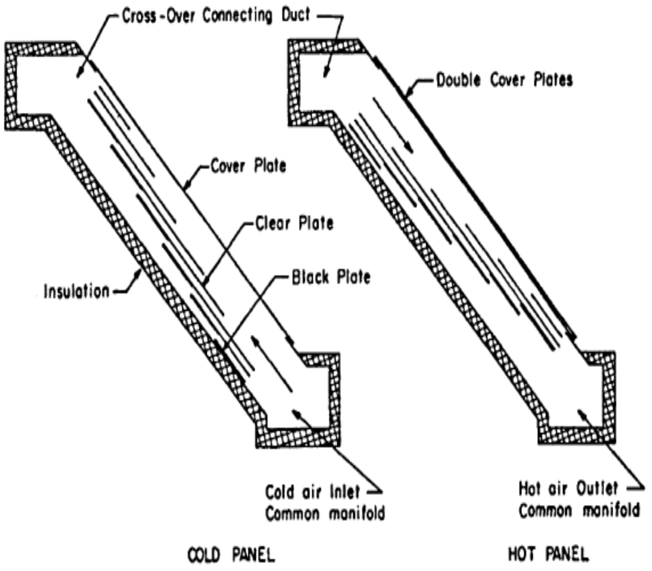

Fig. 7 Air heating collectors from the Colorado Solar House [5]

1960's, solar energy was developed in India as a means of cheap energy for crop drying. Gupta and Garg [6] tested several designs that used both corrugated absorber surfaces as well as wire mesh packing over the absorber. They showed that corrugated surfaces performed better than those enhanced with wire mesh, achieving a maximum of 65% overall energy conversion efficiency.

A design by Close [23] was able to achieve temperatures of around 65 deg C with a collector efficiency of 50%. This study also investigated the use of corrugated absorber surfaces to maximize heat transfer by increasing surface area, and used a trapped layer of air between the single glazing surface and absorber.

Initial experiments using polymer materials were done by Hillier,[7] who tested glazing made of Tedlar, a polyvinyl fluoride (PVF) film. It was found that, despite higher heat losses from the Tedlar, its improved transmittance compensated. It worked especially well when there was more than one glazing, and only the outer glazing was glass.

Using multiple glazing's, forcing air through jets to create more turbulence to enhance heat transfer near the absorber plate, and circulating air between the glazing's. Satcunanathan and Deonarine [25] also explored passing air between multiple glazing before heating it, and they found collector efficiency gains of 10-15%.

These surfaces are prone of corrosion and fouling especially in the presence of humid air. With the advent of new types of polymers it became possible to experiment with new designs that used materials with much lower thermal conductivity. Interest in polymer materials also occurred with Bansal [8] who tested PVF glazing in the environment for an extended period of time and found increased collector performance with PVF glazing.

Use of pickings to enhance heat transfer were investigated by Choudhury and Garg [9] who achieved a collector efficiency of 70% by using a packing material placed above the absorber plate and allowing air to pass through it. Sharma et al. [24] used a wire matrix packing above the absorber plate to enhance heat transfer.

Improving Convective Heat Transfer and Air Residence Time, Modern air heater designs have focused mainly on improving convective heat transfer at the absorber. Mittal and Varshney [10] investigated using wire mesh as a packing material, with air flowing between the absorber and the second glazing through the mesh, achieving a collector efficiency of 70%.

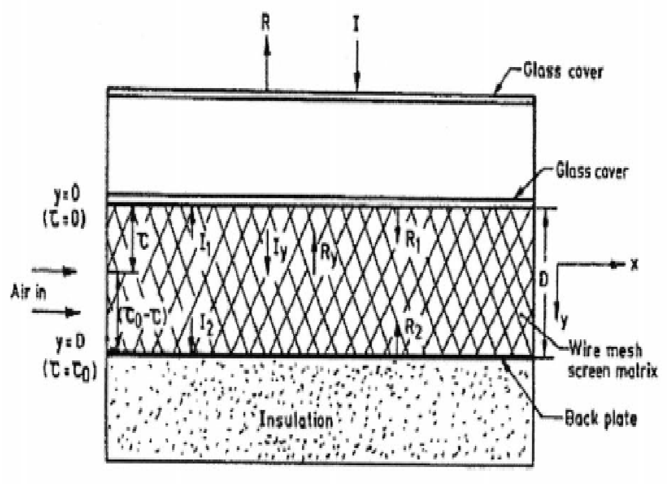

Fig. 8 Flow paths from Mittal and Varshney [10]

Mohamad [11] found that a packed bed of porous media improved heat transfer as well as pre-warming the air by first running it between two glazing plates. This also improved collector efficiency by reducing heat loss to the environment, and helped achieve an overall efficiency, which accounts for pumping losses for moving air through the collector, of 75%

Esen[12] compared several obstacles mounted on a flat plate to a plain flat plate and found that short triangular shaped barriers improved heat transfer efficiency the most by breaking up the boundary layer and reducing dead zones in the collector.

Sahu and Bhagoria [13] used short (1.5 mm) ribs perpendicular to the absorber plate to break up airflow as it went over the absorber plate and ribs

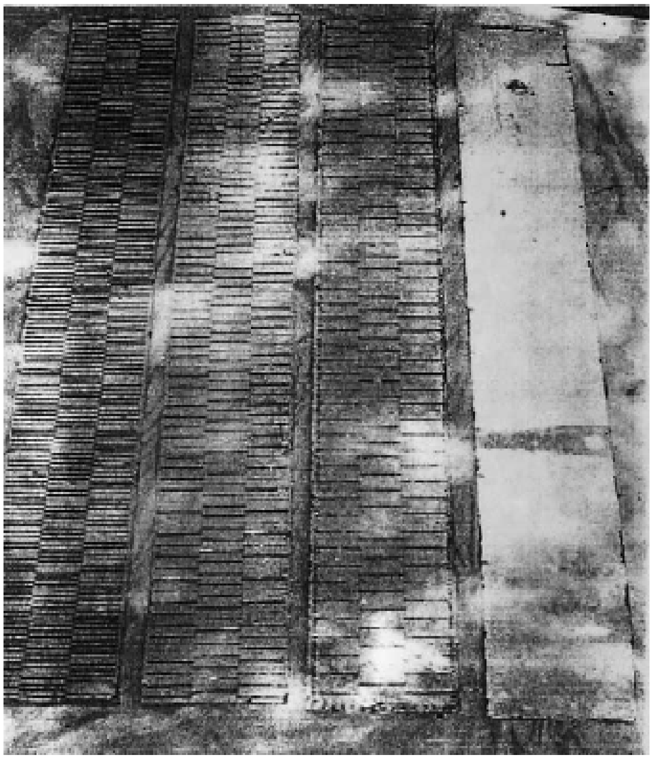

Fig. 9 Roughened Absorber Plates [13]

Romdhane[14] used small extensions from a metal plate to improve mixing of air on the plate. These extensions had the advantage of not increasing pressure drop like packed bed solar air heaters

Ho et al. [15] increased the collector efficiency of a flat metal absorber plate to 68% by running the air above and below the absorber plate

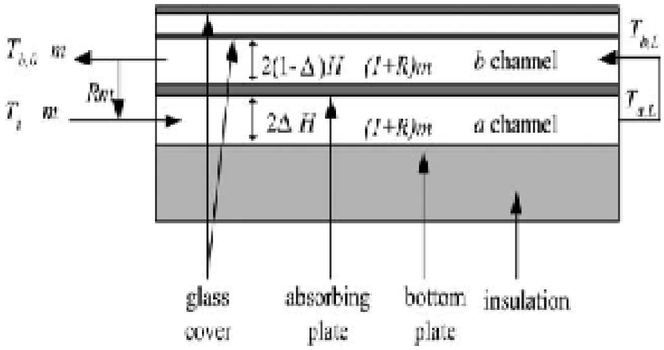

Fig. 10 Flow paths for heater [15]

Ramadan et al. (2007)[16] also reported an efficiency increase using double pass heating in addition to using a limestone packing above the absorber plate and passing air through it.

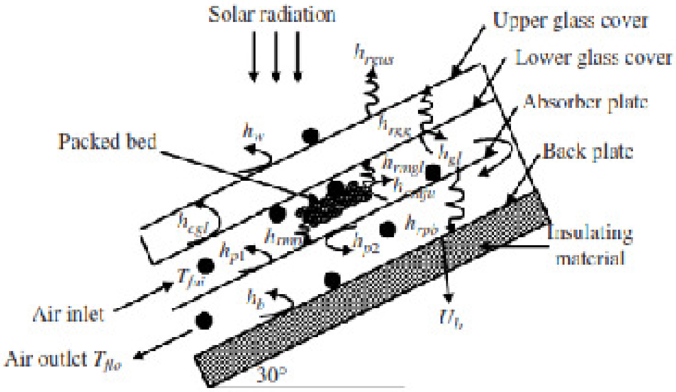

Fig. 11 Flow paths for a packed bed air heater [16]

A selective absorber coating is a coating that has a high solar absorptivity, and low infrared emissivity. These coatings can help improve efficiency by increasing the absorptivity of the absorber plate and decreasing radiative loss. However at low temperature differences between the absorber and the environment, there is little improvement. Hachemi [17] studied the effect of selective surfaces on a solar air heater

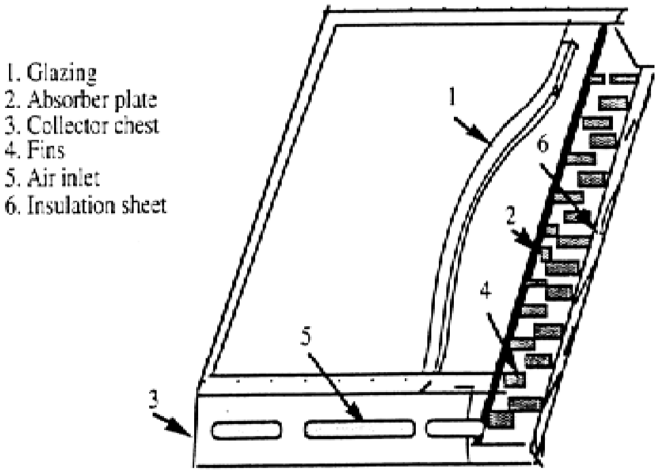

Fig. 12 Configuration of impinging fins [17]

Texieria et al. [18] found a doubling of efficiency for an unglazed flat plate operating at a temperature difference of 70 0C and solar irradiation of 1000 W/m2 using selective surfaces as opposed to non-selective surfaces. This design's greatest enhancement was the addition of a selective surface as opposed to changing the absorber shape or adding glazing or additional insulation.

Liu et al. [19] found only a 5% efficiency increase when using selective coatings on a corrugated absorber in a single-glazed solar air heater using a heavily insulated back plate with air flowing under the absorber. This compares with a reported

20% increase in efficiency by adding corrugation and not using selective surfaces.

Other attempts have been made to improve existing flat plate absorber with limited success. These designs sacrifice efficiency for simplicity. Koyuncu [20] compared several flat plate designs, with one ribbed plate design, and several glazing configurations. The most efficient, at 45.8%, was flat black metal plate with a single polymer glazing, and air passing over the absorber. Matrawy [21] used fins below the absorber plate to enhance heat transfer to the air as it flowed under the absorber, but only achieved 50% collector efficiency. All printed material, including text, illustrations, and charts, must be kept within a print area of 6-7/8 inches (17.5 cm) wide by 8-7/8 inches (22.54 cm) high. Do not write or print anything outside the print area. All text must be in a two-column format. Columns are to be 3-1/4 inches (8.25 cm) wide, with a 5/16 inch (0.8 cm) space between them.

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3. 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.

3.1 Comparison of Performance

The standard metric of a solar air heater's performance is the collector thermal efficiency.
It is defined by,

$$\eta - \frac{\dot{m} c_p (T_{out} - T_{in})}{I_T A_P}$$

Where, terms are defined in nomenclature. It is the energy gain of the airstream divided by the total solar energy incident on the collector. This definition of performance is that used by the ASHRAE 93-2003 Standard for solar collector testing [4] and it defines both the instantaneous and time averaged efficiencies when evaluating dynamically changing solar radiation inputs and temperature profiles.

4. IMPROVEMENT ON MORE BASIC DESIGNS

Other attempts have been made to improve existing flat plate absorber with limited success. These designs sacrifice efficiency for simplicity. Koyuncu [20] compared several flat plate designs, with one ribbed plate design, and several glazing configurations. The most efficient, at 45.8%, was flat black metal plate with a single polymer glazing, and air passing over the absorber. Matrawy [21] used fins below the absorber plate to enhance heat transfer to the air as it flowed under the absorber, but only achieved 50% collector efficiency.

4.1 Comparison of Designs in Academic Literature

When evaluating the performance of different solar air heaters it is necessary to take into account a variety of parameters. Performance data varies widely among academic literature. The following table summarizes some air heaters for which the necessary performance parameters if given with other important operation and performance parameters listed if known. Some values in the table were calculated from other parameters.

Table No. 1 Operating conditions of solar air heaters in literature.

Author	d_h m	$\dot{m}$ kg/s	Re_{d_h}	I W/m^2	T_{out} ^{o}C	$T_{out} - T_{in}$ [^{o}C]	H
Romdhane [14]						60	80%
Sahu and Bhagoria [13]	0.044	0.0164	8000	815	53	12	79.5%
Mohamad [11]							75%
Ramadan et al.[16]	0.214	0.0105	1026	662	68.5	38.5	45.3%
Mittal andVarshney[10]	0.047	0.025	6291	600	48	18	70%
Ho, Yeh, and Wang [15]	0.086	0.0214	6693	1100			68%
Satucunanathan and Deonarine[25]	0.073	0.0418	5378	850		23.8	68%
Esen [12]		0.02		900	28.9	23.3	53%
Close [23]	0.157	0.2842	31091	504	54.4	30.8	40%
Sharma et al. [24]	0.328	0.0165	1627	900	50	14	50%
Matrawy [21]	0.095	0.0140	1459	800	63	33	50%
Koyuncu [20]				1000	45	15	46%
Chafik [22]	0.011	0.0006	2411	800	48	22	40%

5. ACKNOWLEDGEMENTS

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