

PERFORMANCE OPTIMIZATION OF SOLAR AIR HEATING SYSTEM USING DIFFERENT ABSORBER PLATES

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ABSTRACT

Solar Air Heater (SAH) is a device which is mostly used to heat air in cold climates. That heated air has lots of applications including warming building, agricultural producer etc. In present work, an experiment of work has been done to see how a Solar Air Heater (SAH) can be made more effective. This study examines the thermal performance of a Solar Air Heater (SAH) with a W- discrete, V – discrete, and a plain absorber plate at various mass flow rates. Outlet air temperature and thermal efficiency were two experimental outputs that were evaluated to find the performance. At a mass flow rate of 0.049 kg/s, the W – discrete absorber plate SAH was found to have a maximum thermal efficiency of 83%, which is respectively 39.83% and 30.16% greater than the W – discrete and V- discrete SAH. This study showed that for the parameter under consideration, flow configurations with W – discrete and V- discrete solar plate outperform and smooth plate SAH in terms of thermal performance. The angle at which air strike V – discrete absorber plate is 60°, where as the air has to strike two 60° angled plate for the case W-discrete absorber plate. As the friction factor has high value for two 60° in (W-discrete solar plate). The thermal performance of absorber plate with W- discrete is high.

Keywords: SAH, Heat Exchanger, Solar Air Heater, Absorber Plate, Heat Transfer Rate, Thermal Efficiency, Friction Factor.

1. INTRODUCTION

It is impossible to imagine any civilization without energy sources. Energy is required for industrial development, agricultural applications, and domestic tasks. It can take many forms, including chemical, electrical, mechanical, heat, nuclear, and light energy. In industry, wood was the primary source of energy. After the invention of the steam engine, coal became the preferred fuel. The invention of the internal combustion engine resulted in a massive use of petroleum products (petrol, diesel, natural gas, etc.) to meet our energy needs. The fossil fuels (coal, oil, and gas) provide energy that can be converted to other forms of energy [1]. Because conventional energy sources are finite, proper utilization of renewable energy sources such as solar, wind, biomass, and tidal has become critical for the well-being of future generations. The current chapter discusses energy sources, their relative advantages, disadvantages, and applications. Because the current work is focused on improving the performance of solar desalination, the fundamentals of solar desalination have also been discussed in this chapter with a primary focus.

Classification of Energy Sources

Energy source are classified following types.

1. Based on Usability of Energy

Primary energy sources: These sources give a net supply of energy, e.g. oil, coal, uranium etc. The energy required to get these sources is very low than the energy we get from them through the chemical reaction or combustion.

Intermediate resources: The primary energy resources are generally not suitable for ultimate use. These are obtained from primary energy transformed to intermediate by one or more process and are used as vehicles of energy.

Secondary energy resources: The form of energy which is finally supplied to a consumer for utilization (consumption) is called secondary or usable energy, e.g., electrical energy, thermal energy, chemical energy, etc. some energy form may be classified both intermediate as well as secondary resources these are electricity and hydrogen [3].

2. Based on traditional use

The term "conventional energy resources" refers to energy sources that have been in use for many years and were still in use between 1950 and 1976. Examples of these sources include coal, petroleum products, natural gas, hydropower, nuclear fission fuels, etc.

3. Based on long-term availability

Non-renewable resources: The opposite of renewable resources are non-renewable resources. These are derived from resources that, once consumed, cannot be easily regenerated. They can be divided into two categories: uranium and fossil fuels.

Renewable resources: These can be replenished in an adequate duration of time, once it has been consumed. Renewable energy is obtained from natural sources like sun, wind, rain, tides, and vegetation etc. and can be repeatedly replenished when are consumed.

4. Based on commercial application

Commercial energy resources: Coal, oil, uranium, and hydro are commonly known as commercial energy resources.

Noncommercial energy resources: Fire wood, animal dung and agricultural waste etc these energy resources used directly without passing through a commercial outlet known as noncommercial resources.

Radiation

Solar radiation is defined as the energy radiated by the sun. The sun is a large sphere of hot gases, the heat begin generated by various kinds of fusion reactions, its diameter is 1.39×10^6 km, while that of the ear this 1.27×10^4 km. The mean distance between the two is 1.496×10^8 km. the sun is large, it's subtends angle of only 32 minutes 0.53° at the earth surface. This is because it is a very large distance.

The solar radiation is following two types.

1. Extraterrestrial solar radiation
2. Terrestrial solar radiation

Beam radiation: Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called direct radiation or beam radiation.

Diffuse radiation: In diffuse radiation is that solar radiation received from the sun after its direction has been changed by refraction by the atmosphere. Because of the solar radiation is scattered in all directions in the atmosphere. Diffuse radiation comes to earth from all parts of the sky.

Reflected radiation: Reflected radiation is the radiation which reflected components comes mainly from the ground and surrounding objects.

Solar Energy

Solar energy is the energy which comes from the sun. There are many ways to use this power, Heating a house, providing electricity, and desalination of seawater. Solar energy is widely available today, because the sun will always shine on the Earth. There are many application of solar energy, these are following:

Application of solar energy

Direct solar energy applications are discussed below:

- (a) Solar water heating
- (b) Space heating
- (c) Space cooling
- (d) Solar cooking
- (e) Solar green houses
- (f) Photovoltaic electric conversion

Advantage of solar energy

There are many advantage of solar energy the seared scribed below:

- (a) Solar energy is a renewable source of energy which can use to produce the electricity direct utilizing of solar light. It can be harnessed in all areas of the world and is available every day.
- (b) Solar energy is eco-friendly. It does not pollute the air by releasing harmful gases like carbon dioxide, nitrogen oxide, or sulphur oxide etc.
- (c) Utilization of solar energy by any renewable sources which is required small amount maintenance cost.
- (d) It can be used to reduce the electricity bills because the solar energy comes free from the sun.
- (e) Solar cells make absolutely no noise at all.

Disadvantage of solar energy

- (a) Solar energy cannot be collected during the night.
- (b) The initial cost of purchasing a solar system is fairly high.
- (c) The efficiency of solar energy can also be impacted by temperature. If the climate is too cold the temperature is low then efficiency of solar system is also low but the climate is too hot the temperature is high then efficiency of solar system is also high.

- (d) Solar arrays require a large surface area it is a major disadvantage where space is at premium.
- (e) Solar power stations do not match the power out put of similar sized conventional power station; they can also be very expensive to build.

2. LITERATURE REVIEW

Gadi Raju et.al [4] investigated that experiments were conducted on a double pass packed bed SAH with encapsulated PCM on its absorber plate capsules in two different geometries, square and circular in cross sections were used. Four absorber plates with capsules in inline and staggered grid arrangements were attached one by one to SAH and experimental analysis was carried out with mass flow rate of air changed in between 0.008643 and 0.01454 kg/s. It was found that intensity of solar radiation steadily increases before noon, reaching to its maximum at noon and decreases after the noon. Accordingly, absorber plate temperature and PCM temperature in capsules were recorded as higher compared to other temperatures in the experimental setup during charging period, that is, from 10:00 AM to 2:00 PM. • Efficiency of SAH was found to be increasing with increase in mass flow rate of air for all the arrangements.

Nidhul, et.al [5] used numerous types of ribs in SAH, which may be useful for future research. Heat transfer has been significantly improved at the expense of a pressure decrease that is insufficient to compensate for the advantages. Energetic performance analysis is carried out in addition to energy analysis to evaluate the many types of energy losses that occur in a SAH.

Tarek Kh. et al. [7] suggested that SAH quality has been proven to be improved by artificial roughness in the shape of repeating ribs. Ribs interrupted the viscous sub-layer and created local wall turbulence without stopping the principal turbulent stream, resulting in an increase in the convective heat transfer coefficient between the air and heated surface as a result of fluid separation and reattachment. As a result, in this investigation, a SAH roughened with aluminum broken arc ribs was covered with a novel solar selective coating composed of 4% CNTs/CuO black paint.

Aamir Imtiyaz et al. [8] worked for finding out nusselt number and Friction factor are also functions of Re , e/D , P/e , Rib shape, and Duct form, according to the literature review. The roughness height should be slightly greater than the thickness of the transition sub layer. In addition, sloping ribs are recommended to reduce the creation of stationary vortices, improving the effectiveness of the solar air heater.

Kumar D. et al. [9] showed a solar air heater duct, artificial roughness on the underside of the absorber plate promotes heat transfer from the collector to the air in a cost-effective and cost-effective way This study looks at the thermal and thermo hydraulic efficiency of a solar air heater with many v-shaped wire rib roughness on the bottom of the absorber plate, also known as "effective efficiency." When comparing solar air heaters to plane heaters, the study indicated a considerable boost in thermal efficiency. Increasing thermal efficiency is accompanied by a large increase in the pumping power required due to the increased friction factor.

Ho et al. [10] researched whether using a cross crinkled dual run collector plate may improve heat transfer efficiency. The heat exchange area is doubled and turbulence is created when a dual pass appliance with welding cross corrugated captivating plates is used instead of a flat plate device, giving in a significant increase in efficiency.

After an extensive review of various kinds of ribs employed in SAH, this article reports the concise summary which may be of use for future research. Significant enhancement on heat transfer has been achieved at the expense of pressure drop not large enough to offset the gains. Apart from energy analysis, energetic performance analysis is carried out to assess the different kinds of energy losses occurring in a SAH. The impact of ribs on the energy gain of SAH is also reviewed

Objective

1. Increase the solar air heater's surface area for heat transfer.
2. Induce air turbulence inside the solar air heaters duct.
3. Use a double pass solar air heater rather than a single-pass model.
4. Raise the solar air heaters outlet temperature and thermal efficiency.

3. METHODOLOGY

Step-wise details of Research Methodology

Step-1: Identification of Research problem: As the study challenge is "An experimental investigation of a double pass solar air heater with rectangular duct having artificial roughness on the absorber plate," the first step has already been completed. For experimental work, it has been decided to employ discrete W-shaped copper wire to provide artificial roughness on the absorber's top and bottom sides.

Step- 2: Review of literature: The review of the literature, which is the second step, has been finished with the most recent studies to date and is continually being updated. This informs us of any gaps and developments with solar air heaters worldwide.

Step 3- Experimental set-up and its fabrication: It comprises of the fabrication of whole experimental set-up. It includes: Duct Fabrication: It has been done as per standards.

Step-4: Data collection: Following manufacturing, data on the temperature of the absorber plate, the surrounding environment, and the temperature at the exit, the pressure differential, and the mass flow rate will be gathered. These data will be utilised to calculate the thermal and thermo hydraulic parameters. Through an experiment conducted on a smooth plate, the Dittus-Boelter and Modified Blasius equations are used to validate the setup.

Step-5: Data Analysis and Processing: After data collection of all the plates, data analysis and processing will be there so as to get the best result out of all.

Step-6: Interpretation of data by graphs: After data processing, graphs will be formed so as to get the results in a more organized form. Graphs of Nusselt vs Reynolds no., Friction Factor with Reynolds no., Thermal and Thermo hydraulic efficiency with Reynolds No. has been formed, The effect of $\frac{p}{e}$ has also been investigated and it comes to the conclusion that at $\frac{p}{e}$ of 10, the best results come. Also effect of gap has been studied and it has come to notice that relative gap width (g/e) of 1.0 yields the best outcomes than others.

Step-7: Correlations are created after completing the process and determining the intended outcomes in terms of efficiency and pressure decrease.

Step-8: After receiving all of the results, the report writing process will be the final stage.

Following a quick assessment of several studies conducted by knowledgeable researchers, it was discovered that adding ribs and artificial roughness to an absorber increases friction and the coefficient of heat transmission. Numerous studies have been conducted to date to determine the impact of adding ribs across the absorber plate of a single pass solar air heater on the heat transfer coefficient and friction factor. Ribs or machined smooth surfaces are typically used to produce artificially rough surfaces.

Experimental Setup

The fabricated experiment set up view in figure below. It has a rectangular channel which is having a two passes and solar radiation which gives the equivalent heat on plate provided a sun with concentrators outside, a device for measuring pressure, a device for temperature measurement and a blower. A rectangular channel or box which is designed a double passes solar air heater, verify friction factor and heat transfer characteristics over the absorber plate. The whole set up fabricated from wood has a rectangular shaped double passes channel. Absorber plate G.I material (galvanized iron) and painted a black colour, sheet of thermocouple used as insulator in a rectangular box.

The dimensions of the rectangular channel areas follow.

$L \times B \times H$ 1500 mm \times 700 mm \times 70 mm

Solar Air Heater Duct

The fabrication of the duct is done by a wooden plank which is rectangular in cross section. The duct dimension is 1500 mm \times 700 mm \times 70 mm. The aspect ratio of the duct calculated is 45.45. The test section length is 1200 mm. The bottom portion of the duct is fabricated of thick plank of wood with 5mm thick plywood affixed on it and the other two sides is fabricated of 19 mm thick plank of wood.

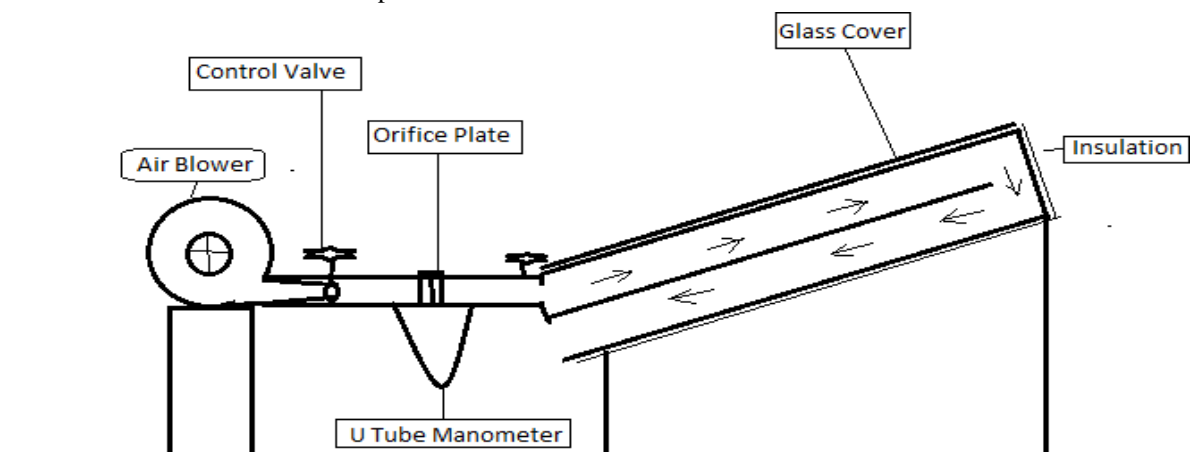


Fig 1: Schematics Diagram of System

4. RESULTS AND DISCUSSION

Experimental Data Reduction The data includes thermocouples reading and different mass flow rates (m). This data have been recorded air inlet temperature and air outlet temperature at a top of absorber plate to the bottom of absorber plate ,a data obtained in steady condition .The data obtained from experiment has been used to calculate heat transfer rate(Q), Nusselt number (Nu), friction factor (f),and Reynolds number (Re).The following equation has been used to determine the Q ,Nu ,f and Re.

Experimental Readings

S.No	Time	Radiation (W/m ²)	T _{amb}	T _i	T _p	Plain Plate Solar Air Heater			VGap Solar Air Heater			WGap Solar air Heater		
						m1	m2	m3	m1	m2	m3	m1	m2	m3
1	10:00AM	686	27.6	28.7	58.75	31.4	30.8	30.5	33.5	32.4	31.8	37	35.6	34.5
2	11:00AM	710	28.2	29.7	66	33.6	32.6	32.3	36.4	35	34.2	41.4	39.2	38.3
3	12:00AM	803	31.3	32.2	72.75	37.2	36	35.5	40	38.2	37.6	47.2	44	42.3
4	1:00PM	945	33.9	35.3	75.75	42.8	41	40.4	45.3	42.7	42	53.4	51	49
5	2:00PM	880	31.5	32.2	74.75	38.7	37.1	36.7	39.4	38.7	37	48.5	45	43.4
6	3:00PM	835	27.4	28.2	68.5	34	32.6	32	34	33.5	32.2	42	39	37.3
7	4:00PM	673	26.8	28.5	63.25	31.7	31	31	32.6	32.4	31.3	38	35.5	35

Figure shows the outlet Nusselt number vs Reynolds number on the testing day(4) for various solar air heaters at mass flow rate . The outlet Nusselt number rose from morning to midday and then began to fall towards evening. The main reason for the trend was variation in solar radiation with time.

The output Nusselt number increased as the mass flow rate of air increased for all the three solar air heaters with the different types of absorber plates (plain plate, V –Discrete plate, W-Discrete plate).

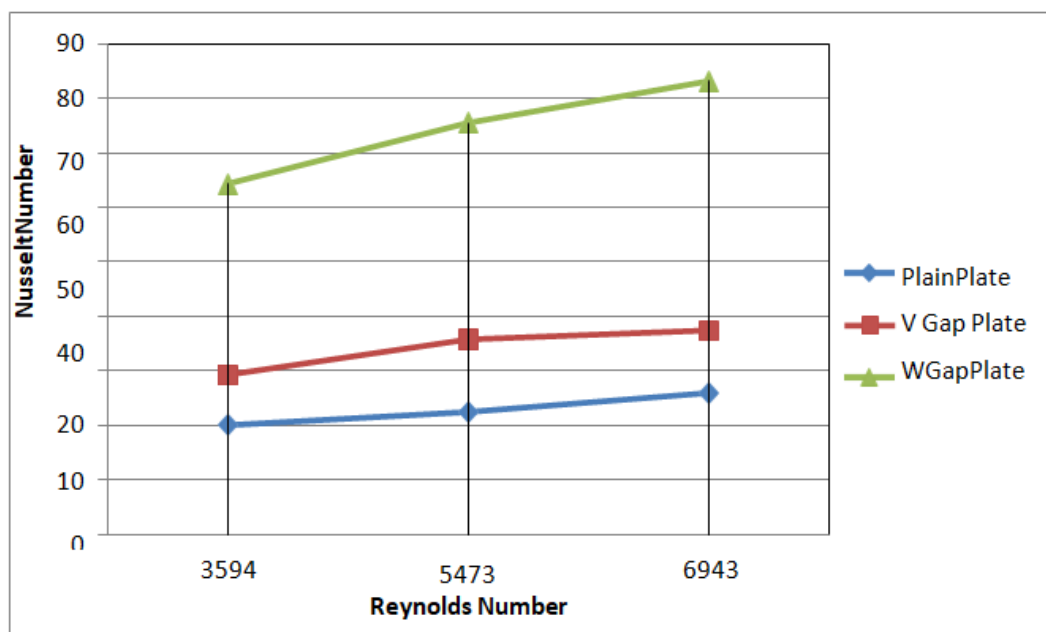


Fig 2: Comparison between Nusselt number & Reynolds number for different absorber plate

Maximum outlet Nusselt number was found out for Plain plate, W – Discrete plate and V-Discrete plate with the values of 64.293, 75.495 and 83.128 respectively at temperature. Minimum outlet Nusselt number for above three solar airs heater was calculated to be 29.253, 35.744 and 37.397respectively at temperature. Again the reason was amount of solar radiation falling of the air heaters.

5. CONCLUSION

An experimental analysis on performance of conventional W-discrete and V-discrete absorber plate in double pass solar air heater (DPSAH) having the air flow on absorber plate has been made for air mass flow rate of different 0.025 kg/s, 0.037 kg/s and 0.049 kg/s. The following are the major conclusions that are drawn.

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