Performance Analysis of Solar Air Heater with Finned Vertical Absorber

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Abstract - *Solar air heating is a technology which works on the renewable source of energy, but when we compare it on the basis of fuel and other performance aspects, then it attracts attention of the people. The performance of the solar air heater can be influenced by various numbers of factors that will come in to picture only when we analyze both energetic & exegetic aspects of traditional design. Recent studies on this topic covers design, performance assessment, heat transfer enhancement, numerical work, experimental work, thermal heat storage, and effectiveness compassion. And also, we cannot ignore the possibility that to enhance performance efficiency nearly from 48% to 88% if we go with exergy analysis. But our main concern is to work on the basic design of the solar air heater by following below key words, that is*

Key Words: Solar energy → solar air heater → active heating → with fins.

1. INTRODUCTION

Solar air heater is one of the basic equipment through which solar energy is transformed into thermal energy. Flat plate SAH's are the universal services for interception solar heat at low temperature, and it had been utilized widely for applications of air heating. Renewable energy has been in the centre of interest in recent researches because of the crucial need of energy, its availability and less resulting pollution compared with other energy resources. Solar energy is one of the main clean energy resources among all different renewable energy resources, which can satisfy a great part of energy demand in our society without any negative effects on the environment. Nowadays, SAH's are used. As one of the solar energy collection systems due to its simple design, construction, very low cost, and easy maintenance. The performance of the SAH is affected, by many parameters such as climate conditions, dimensions of the solar collector, type and design of the absorber plate, glass covers, and insulation material.

1.1 Research Gap

1. The value of the heat transfer coefficient between the air and the absorber plate reduces the thermal efficiency of solar air heaters.
2. Another reason for the low thermal performance of solar air heaters is heat loss through the top cover (the glazing), as all the sides and the bottom of the collector are thermally insulated.
3. Low thermal efficiency due to the lack of heat transfer from the absorber plate to the flowing air.
4. The mismatch between the availability of solar radiation during the day and the increase of thermal heat demand during night.
5. The low thermal conductivity of the air and the surface area of the absorber plate. But these limitations can be tackled by increasing the heat transfer area through the use of the extended surface (fins), matrix or porous bed absorbers.
6. The short settling time of flowing air inside the SAH. This limit can be decreased by increasing the air pass length through the using of double air pass.
7. The weakness of the heat transfer between the flowing air and the absorber plate. It could be overcome by creating turbulent flow inside the flow channel by using corrugated surfaces or baffles or packed bed material.
8. Enhancement of the heat transfer process in the single pass SAH can be achieved through the using of fins or obstacles which produce turbulent flow under the absorber plate.

1.2 Problem Identification

All through all these reviews we can observe that there is very less work is being carried out with design point of view since the major problem with the traditional design is that it is very large in size, as well as non-flexible to solar irradiation. We need to put traditional design fixed in front of sun and have to be dependent on atmospheric and geographic condition. Thus, these limitations open doors for me for my modified conception design. My objectives for modified conception design are listed below.

- ❖ To provide greater amount of solar radiation by using reflective glass.
- ❖ To provide natural convection for the design by which it reduces blower work since it uses vertical type absorber.
- ❖ Use of transverse ribs on the aluminum fins will help in heat enhancement.
- ❖ To make design as effective and economical as possible.

2. EXPERIMENTAL SETUP

The proposed collector was manufactured and tested under weather circumstances of Mehsana town (23.6oN, 72.4oE), Gujarat. As shown in figure above, we are using a concentric type of solar reflectors which will reflect the solar radiation to the vertical type double pipe or concentric type absorber, here an air which is been passing through spacing between two adjacent fins of annulus will get heated by reflected solar radiation. Here an additional heat storage works after the sun set given at spacing of inner tube. Air flow rate can be controlled by blower head which is been given at the top of the absorber pipe.

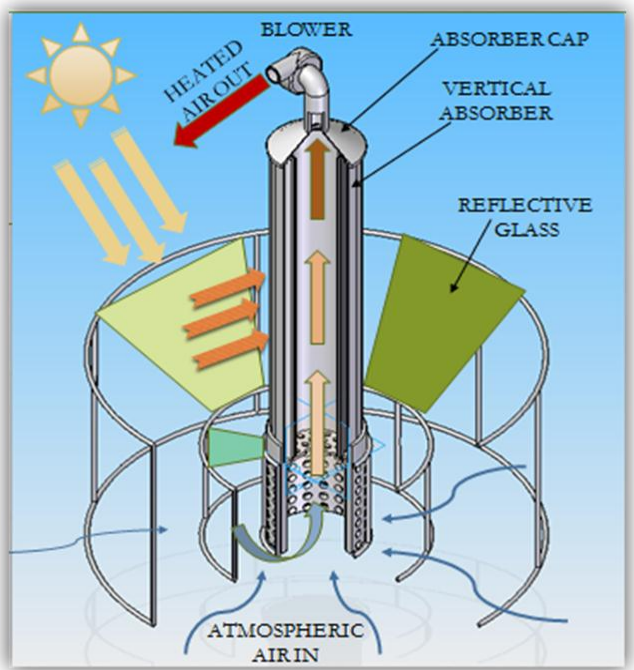

Fig-1: A complete assembly of conception design.

Pyranometer model MS-802 (sensitivity of 7.03 μ-volts/W m2) was used to measure the global solar radiation (I). All experiments were started at 9 am and continued until all measured temperatures equal to ambient temperature. Thermo-physical properties of the paraffin wax are given below.

Table -1: Thermo-physical properties of the paraffin wax

Sr no	Parameter	Paraffin wax
1	Melting temperature	54 oC
2	Latent heat of fusion	190 kJ/kg.
3	Thermal conductivity	0.21 W/m.oC
4	Solid density	876 kg/m3
5	Liquid density	795 kg/m3
6	Heat capacity	2.1 kJ/kg.Oc

2.1 Experimental procedure

- ✓ The measured variables were recorded every hour. The variables include: air flow rate, solar radiation, ambient temperature, inlet and outlet air temperatures, temperatures of air inside the SAH, and temperature of absorber cylinder at many selected locations.
- ✓ Air blower, 1500 W, is used to blow air in SAH with a maximum volume flow rate of about 1500 m3/h. The amount of air flow rate is controlled by changing blower rational speed.
- ✓ A calibrated orifice meter, a bellows meter of 0.05 m3 resolution, a stop watch, and U-tube manometer are used to measure the flow rate of the air.
- ✓ A mercury thermometer of 0.20 ºC resolutions is utilized to measure the temperature of ambient air.
- ✓ Copper–constantan thermocouples are utilized to measure the temperatures of air inside the SAH.
- ✓ A thermocouple is placed at the centre of the inlet section to measure the temperature of flowing air at inlet. The temperatures of air flows along the SAH tube are measured by equally spaced five sections. For each section the average air temperature is obtained as the arithmetic mean of the three-thermocouple probe readings along cross-section [(TA+TB+TC)/3].
- ✓ To have the same ambient and experimental conditions, two SAHs with different specific heat capacity storage materials are compared at the same time. In this experiment, the air flow rate was varied from 0.05 to 0.3 kg/s.

2.2 Efficiency calculation of solar air heater

Efficiency of solar air heater can be calculated by,

$$\eta_{th} = \frac{\text{Useful energy delivered}}{\text{Total incoming solar energy}} = \frac{Q_u}{A_p I_c}$$

Where,

Ap =black absorber plate area (Square meter).

Qu = useful heat gain (Watts).

Ic = solar irradiation.

$$Q_u = \dot{m} c_p (T_{out} - T_{in})$$

Cp = specific heat of air (J/Kg.K).

m = mass flow rate, (kg/s).

Tin = air inlet temperature, (K).

Tout = air outlet temperature, (K).

3. SIZING

Before going for experimentation, I have taken a traditional design data for comparison as well as sizing of the traditional design.

Table -2: Sizing for traditional design

SIZING FOR TRADITIONAL DESIGN				
Details for parts, size and type of material FPSAH.				
Parts	**Size**			**Type of material**
	Length (mm)	**Width (mm)**	**Height/ Thickness (mm)**	
Solar air heater box	1400	300	140	Glass Wood, Coated with black paint
Absorber plate	1400	300	1	Aluminium, Emissivity of 0.9, Absorptivity of 0.9, Coated with black paint
Glass cover	1400	300	3	Glass, Transmittivity (0.9), Emissivity (0.85)
Entry section for Air	Día 600mm			Aluminium
Exit section for Air	Día 400mm			Aluminium

And for our design we adopted the same size of absorber plate but change in assembly. These sizing's are carried out by simple calculations,

Total absorber area exposed to sun of traditional SAH = 1400mm x 300mm

=4, 20,000mm2.

Thus, we can use that much area only for our comparison but as shown in figure below, in our design only fins are exposed to solar radiation thus fin area must be equal or less than area available for design. It is also found that the operation of the FPSAH extended up to 4 hours after sunset with outlet temperature reach 8.6 ºC more than ambient when 39 kg of paraffin wax is used as latent heat storage. But if we design our model for 39kg of wax than it is not possible to compare it with traditional one. Thus, for design point of view we are reducing wax filling to 13 kgs. By fixing it now we are capable to size inner cylinder whose dimensions will be Día 200mm and length as 668mm. if we go for cylindrical design only than area exposed to solar radiation will be

= pie x Día x Length.

=3.1415 x 200mm x 668mm

=4, 19,704mm2 ----------------- (1)

Table -1: Sizing for our connectional design

Sizing for cylindrical vertical Absorber					
Parts	**Material requirement size**			**Quantity**	**final size**
	Width	**length**	**thickness**		
Vertical cylindrical absorber	628.31	668.45	1	1 no	Dia 200*668 mm
fin	100	668.45	1	12 no's	100*668 mm
acrylic glass tube	Greater than 300mm	Less than 350mm	3	1 no	inner dia 290mm, outer dia 300mm
Conical protrusion	Base Dia=4mm	Height=4 mm	1	205 no's/fin	2460
Entry section for Air	PVC REDUCER OF 140MM X 110MM.			1no	140mm x 110mm
Exit section for Air	PVC COUPLING OF ID: 25MM OD: 30MM.			1no	id: 25mm od:30mm

These sizing's are carried out by simple calculations,

Total absorber area exposed to sun of traditional SAH = 1400mm x 300mm

=4, 20,000mm2.

Thus, we can use that much area only for our comparison but as shown in figure below, in our design only fins are exposed to solar radiation thus fin area must be equal or less than area available for design. It is also found that the operation of the FPSAH extended up to 4 hours after sunset with outlet temperature reach 8.6 ºC more than ambient when 39 kg of paraffin wax is used as latent heat storage. But if we design our model for 39kg of wax than it is not possible to compare it with traditional one. Thus, for design point of view we are reducing wax filling to 13 kgs. By fixing it now we are capable to size inner cylinder whose dimensions will be Día 200mm and length as 668mm. if we go for cylindrical design only than area exposed to solar radiation will be

= pie x Día x Length.

=3.1415 x 200mm x 668mm

=4, 19,704mm2 ----------------- (1)

Which is lesser than our limitations so that is also desirable condition, but for better performance we are using 12 numbers of fins with ribs of 4mm Día and 4 to 6mm length and 16mm pitch arranged in discrete pattern with staggered arrangement? Since these attached fins whose width is 100mm and length 668mm, will shadow the storage cylinder thus.

New exposed area will be = no of fins x fin width x fin height.

=12 x 100mm x 668mm

= 8, 01,600 mm2 ----------- (2)

By summing this equation (1) & (2), we will get total aluminium portion used that is

=**1221304 mm2.** (25% aluminium surface will not see the direct solar radiation due to self-shadow by fins)

=9, 15,978mm2. (Remaining 75% aluminium surface)

No of pin protrusion in each row = 3 nos.

No of pin protrusion in each column = 66 nos.

Total no of pins on each fin = 198 nos.

Total no of pins on 12 fins = 2376 nos.

4. RESULT& DISCUSSION

Fig-2: A complete assembly of Actual design.

Here total six number of experiment was conducted from 9 am to 8 pm every day in the month of April. The following measurement has been recorded that is air flow rate, temperature of air inside the annulus, solar radiation, and ambient/atmospheric air temperature. Inlet and outlet air temperature and also wind speed. Variation for wind speed was from 0 to 3 m/s for various days and solar radiation was ranging from 40 to 1000 W/m2. And the average annual normal solar radiation for tested location (Mahesana) was found to be 5.87kwh/m2/day. The experiment was conducted for six different conditions to get the best efficiency. The measured conditions for vertical type solar air heater are tabulated in the table. Here among six experimentations first three were performed with specified mass flow rates that is 0.0221, 0.0279 & 0.0349 kg/sec, that is at a speed of 1.9m/s, 2.4 m/s & 3m/s respectively. From the data extracted from experimentation it is clear that temperature difference between inlet and outlet will increase with increase in solar radiation. From the six cases cross sectional area is same for all cases but the only thing that effects efficiency is mass flow rate, from the readings it is very clear that with lower mass flow rate temperature difference will be maximum but not efficiency. For optimum efficiency flow rate must be high. For last three conditions use of phase change material results in temperature rise by 2.5 degree Celsius, & reduces efficiency by 2.12%, and extends working hours by approx. 2 hours by using 10kgs of PCM. From the table it can be say that for day-01 at Day Average solar intensity 631 W/m2, and air mass flow rate of 0.0221kg/sec, the maximum temperature difference was about 17.7 degree Celsius for vertical type solar air heater without PCM, average temperature of absorber plate was 62.3°C & with day average efficiency of 76.05%. day-02 at Day Average solar intensity 641W/m2, and air mass flow rate of 0.0279kg/sec, the maximum temperature difference was about 14.29 degree Celsius for vertical type solar air heater without PCM, average temperature of absorber plate was 55.5°C & with day average efficiency of 78.7%. day-03 at Day Average solar intensity 715W/m2, and air mass flow rate of 0.0349kg/sec, the maximum temperature difference was about 14.63 degree Celsius for vertical type solar air heater without PCM, average temperature of absorber plate was 55.32°C & with day average efficiency of 78.93%. day-04 at Day Average solar intensity 773.2W/m2, and air mass flow rate of 0.0221kg/sec, the maximum temperature difference was about 19.94degree Celsius for vertical type solar air heater with PCM, average temperature of absorber plate was 62.5°C & with day average efficiency of 71.83%. day-05 at Day Average solar intensity 789.8W/m2, and air mass flow rate of 0.0279kg/sec, the maximum temperature difference was about 17.3 degree Celsius for vertical type solar air heater with PCM, average temperature of absorber plate was 58.65°C & with day average efficiency of 75.4%. day-06 at Day Average solar intensity 861W/m2, and air mass flow rate of 0.0349kg/sec, the maximum temperature difference was about 16.51degree Celsius for vertical type solar air heater with PCM, average temperature of absorber plate was 59.53°C & with day average efficiency of 80.17%. From the graph we can see the variations of the hourly temperature difference of air for specified three mass flow rates with and without using PCM. We can observe from graph that from 9 am to 1 pm, temperature of the complete assembly increases, after that temperature of air is reducing. According to most of the cases temperature difference of flowing air is maximum between 12pm to 2 pm that is because of maximum solar radiation available. We can also observe that temperature difference is higher with low air flow rate and lower with high air flowing rate. But efficiency is lower with low air flow rate and higher with high air flow rate. It means we need to set our parameter as our requirement. The energy loss by heat transferred to fluid will increase if we increase mass flow rate of air, because high Reynolds number will increase the intensity of turbulent flow that will help to enhance better heat transfer to air. Here highest average efficiency was 80.17% that was achieved by experimental setup for day-6, and if we consider working hours as well than experimental setup day-4 is best, since it gives additional 2 hours for working.

5. CONCLUSION

The experimental evaluation of solar air heater with finned vertical absorber was done at Mahesana, Gujarat. And I come on the conclusion that changing the traditional concept with cylindrical tube and eliminating insulation from it is definitely changes the performance. The result indicates that the highest efficiency was achieved for setup no-6, and that is 80.17%, for flow rate of 0.0349 kg/s, and day average solar irradiation of 808W/m2. And with the mass flow rate of 0.0221 kg/s and usage of 10kg PCM will lead to give time rise of 2 hours. More research may be carried out by altering number of fins, increasing height of absorber cylinder, or by modifying to multi-pass system for air flow.

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