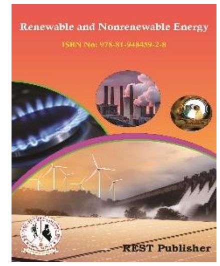
Renewable and Nonrenewable Energy

Vol: 5(1), 2026

REST Publisher; ISBN: 978-81-948459-2-8

Website: https://restpublisher.com/book-series/ese/

DOI: https://doi.org/10.46632/rne/5/1/14



Experimental Analysis of Double Pass Solar Air Heater with Different Inclinations

K. Kalyani Radha, B. Omprakash

JNTUACEA, Ananthapuramu, Andhra Pradesh, India.

*Corresponding Author Email: *radha.mech@jntua.ac.in*

***Abstract**: There is an ever-increasing demand to a device a system for drying cultivated crops in remote areas at a cheaper cost. Solar air heaters (SAH) have been satisfying this need for the past few years and different models have been developed to improve its efficiency. The increase of global warming due to fossil fuel consumption extent can be reduced. In addition to agricultural sector, SAH has been finding its application in power plants and processing industries for drying purpose and room heaters in winter season. This project deals with the fabrication and testing of an improved version of a solar air heater. The improved version has increased heat-transfer area which is achieved by incorporating double pass pattern with fins on both sides. This is an existing single pass solar air heater. The absorption characteristics are improved by using a polyester coating. It is proposed to conduct a performance analysis of double pass pattern solar air heater with different inclination angles and different fin materials.*

Keywords: *Solar air heater, fins, double pass solar air heater.*

1. INTRODUCTION

This century has started inviting renewable energy technologies (RETs) to bridge the gap between mounting global energy demand and dwindling supply of finite conventional energy source. Popular awakening on cleaner environment encourages RETs in industrial and agro processing-confidence created. But real benefits of RETs are not accessible to global population. Because of uncompromising economics, international efforts for maximizing the efficiency and minimizing the cost RETs are being taken. India spends annually around 157 Million Tons of coal, 89 Million Tons of petroleum products and 233 Million Tons other traditional conventional energy to meet its industrial, agro and domestic requirement. Around 300-400 million Tons of oil imports and 800 million Tons of coal import in addition to the local resources will be needed in 2030 to sustain 8% growth rate in the country. Conventional energy is exhaustible, polluting and also responsible for global warming Solar energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar energy technologies include solar photovoltaic and solar thermal electricity, which can make considerable contributions in solving some of the most urgent problems the world now faces. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air. In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared". The International Energy Agency projected that solar power could provide one third of the global final energy demand after 2060, while CO_2 emissions would be reduced to very low levels.

2. LITERATURE SURVEY

Esen [7] presented an experimental energy and exergy analysis for a novel flat plate solar air heater (SAH) with and without several obstacles. It was found that the optimal value of efficiency is middle level of absorbing plate in flow channel duct for all operating conditions and the double-flow collector supplied with obstacles appears significantly better than that without obstacles. The exergy calculations delivered for different SAHs showed that the largest irreversibility is occurring at the flat plate (without obstacles) collector in which collector efficiency is smallest. Using a comparative study on four types of air heaters he showed that given the different operative and atmospheric conditions that can happen in practice, it must be taken into account the possibility of scheming different experiences, in order to determine the influence of the different variables on the collector efficiency and the characteristic parameters of the solar collector. El-Sebaii et al., [6] investigated theoretically and experimentally the double pass-finned plate solar air heater and their results showed that the double pass v-corrugated plate solar air heater is 9.3-11.9% more efficient compared to the double pass-finned plate solar air heater. It was also indicated that the peak values of the thermo hydraulic efficiencies of the double pass-finned and v-corrugated plate solar air heaters were obtained when the mass flow rates of the flowing air equal 0.0123 and 0.0225 kg/s, respectively. Ozgen [11] experimentally investigates a device for inserting an absorbing plate made of aluminum cans into the double-pass channel in a flat-plate solar air heater (SAH). This method substantially improves the collector efficiency by increasing the fluid velocity and enhancing the heat-transfer coefficient between the absorber plate and air. According to the results of the experiments, the double-flow type of the SAHs with aluminum cans has been introduced for increasing the heat-transfer area, leading to improved thermal efficiency. The performance of double-flow type SAHs, in which air is flowing simultaneously over and under absorbing plate, is more efficient than that of the devices with only one flow channel over or under the absorbing plate because the heat-transfer area in double-flow systems is double. Omojaro [12] investigated experimentally the thermal performance of a single and double pass solar air heater with fins attached and using a steel wire mesh as absorber plate was. The effects of air mass flow rate range between 0.012 kg/s and 0.038 kg/s on the outlet temperature and thermal efficiency was studied. Result shows that, the efficiency increases with increasing air mass flow rate. For the same flow rate, the efficiency of the double pass is found to be higher than the single pass. Moreover, the thermal efficiency further decreases by increasing the height of the first pass of the double pass solar air heater. Bhagoria et al.,[3] proved that the presence of ribs (fins) increases friction factor up to 5.3 times, thus increasing the heat transfer when compared to smooth absorber plate and thus increases heat transfer coefficient. Gupta and Kaushik [8] showed that artificial roughness on absorber surface effectively increases the efficiencies in comparison to smooth surface and the increase of heat transfer coefficient is in the following order: Smooth surface < Circular ribs < V shaped ribs < Wedge shaped rib < Expanded metal mesh < Rib-grooved < Chamfered rib-groove and at very high Reynolds number the order is reversed. Rodriguez-Hidalgo et al., [15] performed experimental research to describe the transient behavior of a flat plate collector field under outdoor working conditions. A transient collector model was assembled using thermal resistances and capacitances. Three thermocouples were added to measure the center point temperature of the glass cover, box back surface and absorber plate of one of the collectors. Using this information, the parameters of detailed thermal losses were calculated by applying a dynamic energy balance under the transient regime. Correlations for the external and internal convection heat transfer coefficients were determined experimentally using the measurements of three surface temperatures. Akpinar et al., [1] investigated performance analysis of four solar air heaters with and without obstacles. The experiments were performed for two air mass flow rates of 0.0074 and 0.0052 kg/s. The first and second law efficiencies were determined for SAHs and comparisons were made among them. While the values of first law efficiency varied between 20% and 82%, the values of second law efficiency changed from 8.32% -44.00%.It was also shown that the efficiency of the solar air collectors depended significantly on the solar radiation, surface geometry of the collectors and extension of the air flow line. The efficiency of the collector improved with increasing mass flow rates due to an enhanced heat transfer to the air flow. The efficiency decreased as the temperature parameter increase, meaning at high temperature parameter, the overall loss was lower.

3. DESIGN AND FABRICATION

Fabrication of Casing: Plywood is a sheet material manufactured from thin layers or plies that are glued together with adjacent layers having their wood grain rotated up to 90 degrees to one another. It is an engineered wood from the family of manufactured boards which includes medium-density fiberboard and particle board. The principal function of the core layers is to increase the separation between the outer layers where the bending stresses are highest, thus increasing the panel's resistance to bending. As a result, thicker panels can span greater distances under the same loads. In bending, the maximum stress occurs in the outermost layers, one in tension, and the other in compression. Plywood is used in many applications that need high-quality, high-strength sheet material. Quality in this context means resistance to cracking, breaking, twisting and warping. Exterior glued plywood is suitable for outdoor use, but because moisture affects the strength of wood, optimal performance is achieved in end uses where the wood's moisture content remains relatively low. Sheet metal is simply metal formed into thin pieces and flat pieces. It is one of the fundamental forms used in metal working and can be cut and bent into a variety of different shapes. Countless everyday objects are constructed of these materials. Thickness can vary significantly, although extremely thin thickness is considered foil or leaf and pieces thicker than 6 mm are considered plate. Sheet metal is available as flat pieces or as a coiled strip. The coils are formed by running a continuous sheet of metal through a roll slitter. The thickness of sheet metal is called its gauge. The gauge of sheet metal ranges from 30 gauge to about 8 gauge. The higher the gauge, the thinner is the metal. There are many different metals that can be made into sheet metal, such as aluminum, brass, copper, steel, tin, nickel and titanium. For decorative uses, important sheet metals include silver, gold and platinum. Sheet metal has applications in car bodies, airplane wings, medical tablets, roofs for building and many other things. Sheet metal of iron and other materials with high magnetic permeability, also known as laminated steel cores, has applications in transformers and electric machines. Historically, an important use of sheet metal was in plate armor worn by cavalry and sheet metal continuous to have many decorative uses. The figure shows the flat plate collector which is done by sheet metal. There are two layers of sheet metals in all the sides that are in bottom and sides. The sheet metals are welded with the frame using the welding equipments. *Fabrication of Collector:* The solar radiation is absorbed by the collector plate which is made up of mild steel iron. The specifications of the absorber plate are:

Plate material	- mild steel iron
Plate thickness	- 2mm
Fin materials	- mild steel iron & Aluminum
Fin thickness	- 2mm
No. of fins	- 78
Plate dimensions	- 800mm*580mm
Fin arrangement	- zigzag arrangement
Coating material	- pure polyester

The fabrication of collector consists of the following two distinct stages:

- Welding of fins
- Coating with polyester

Two mild steel iron plates, one for the collector plate and other for the fins purpose were purchased. The plate was cut using a hydraulic shearing machine for 80mm*60mm. Welding of Fins: The fins are welded using arc welding technique to the base collector plate at an angle of 60^0 to the plate using a template which is cut to 60^0.

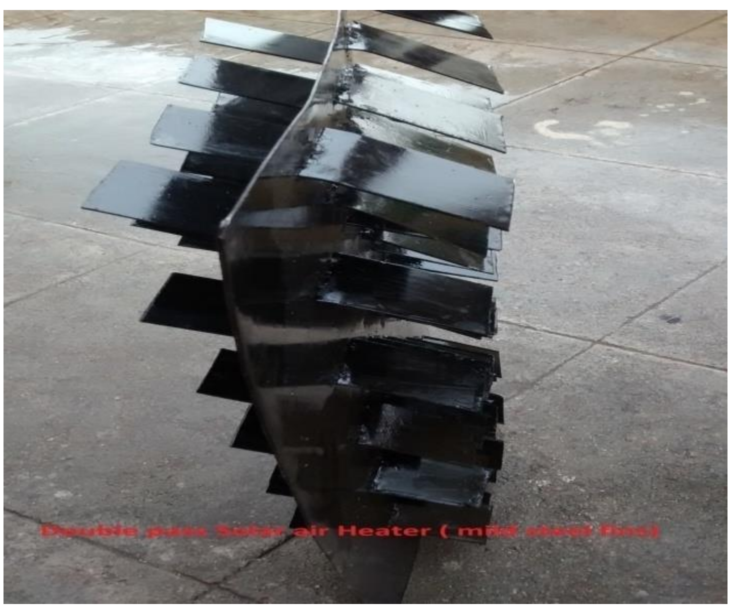


FIGURE 1. MS Fins welded to the base collector plate

Coating with polyester: The finned absorber plate is coated with pure polyester which is shown in the figure. The various processes involved in this coating are:

- Wiping of the collector plate using brushes and removal of foreign particles using high speed air blower
- Application of thinner
- Increasing the surface roughness using emery sheet

- Application of white texture coating on both sides
- Finishing using black matt on one side
- Drying the texture using an air blower
- Painting using liquid polyester

Riveting of aluminum fins: The rest of the experiment is conducted with aluminum fins. The aluminum fins are riveted the base plate with the help of rivets having size diameter 3mm & length 6mm.

FIGURE 2. double pass solar heater with aluminum fins

Properties of aluminum: After the iron, aluminum is the second most widely used metal in the world. The properties of aluminum include:

- Low density and therefore low weight
- High strength
- Superior malleability
- Easy machining
- Excellent corrosion resistance
- Good thermal and electrical conductivity
- Very easy to recycle
- Weight:
- One of the best-known properties of aluminum is that it is light weight, with a density one third that of steel 2.700 Kg/m^3. The low density of aluminum does not affect its strength.
- Strength: Aluminum alloys commonly have tensile strength in between 70 and 700MPa. Unlike most steel grades, aluminum does not become brittle at low temperatures, instead its strength increases. At high temperatures, aluminum's strength decrease.
- Linear expansion: Compared with other metals aluminum has relatively large co-efficient of linear expansion.
- Machining: Aluminum is easily worked using most machining methods- milling, drilling, cutting, punching, bending etc., Further more energy input during machining is low.
- Formability: Aluminum's superior malleability essential for extrusion with the meta either hot or cold, this property is also exploited in the rolling of strips and foils as well as in bending and other forming operators.
- Conductivity: Aluminum is an excellent conductor of heat and electricity. An aluminum conductor weighs approximately half as much as a copper conductor having the same conductivity.
- Corrosion resistance: Aluminum reacts with oxygen in the air to form an extremely thin layer of oxide. This layer dense and provide excellent protection. The layer is self- repairing if damaged.

4. EXPERIMENTAL SETUP

Figure shows the assembled view of various components of the Solar Air Heater model developed. The coated absorber plate is assembled inside the casing. The casing is finally covered with a glass plate to avoid loss of heat content to the atmosphere. Holes of diameter 1.5 inches are made on either side of the casing for air inflow and outflow. At the inlet an Orifice meter is fitted. The Orifice meter is connected to the manometer where the working fluid is water, since the density of air is very low. A centrifugal blower is connected to the Orifice meter to suck air from the atmosphere and force it into the fabricated setup at a higher velocity. Three thermocouples are used for temperature measurement, first being at the inlet, second being at the outlet and the third one over the surface of the collector plate. The temperature is observed with the help of a temperature indicator to which thermocouple connected. The temperature on the plate shows the effectiveness of the plate in absorbing the solar radiation. The temperature of the outlet air shows the effectiveness of the model in transferring heat from plate to air. By calculating the temperature difference between the plate and the outlet air, the efficiency of the model can be understood. The heat flux received from the sun was measured using Solar meter.

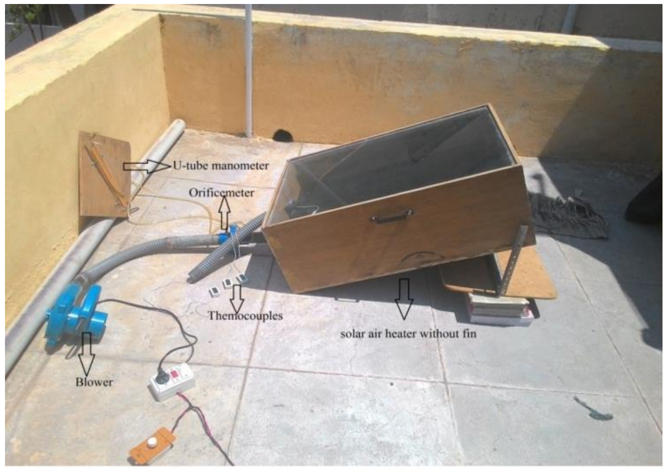


FIGURE 3. Experimental set up without fins

FIGURE 4. Experimental set up with aluminum fins

Orifice meter: An orifice plate is a thin plate with a hole in it, which is usually placed in a pipe. When a fluid passes through the orifice, its pressure builds up slightly upstream of the orifice but as the fluid is forced to converge to pass through the hole, the velocity increases and the fluid pressure decreases. A little downstream of the orifice the flow reaches its point of maximum convergence, the vena contract where the velocity reaches its maximum and the pressure reaches its minimum. Beyond that, the flow expands, the velocity falls and the pressure increases. By measuring the difference in fluid pressure across tapings upstream and downstream of the plate, the flow rate can be obtained from Bernoulli's equation using coefficients established from extensive research. Orifice plates are most commonly used to measure flow rates in pipes, when the fluid is single-phase and well-mixed, the flow is continuous rather than pulsating, the fluid occupies the entire pipe, the flow profile is even and well-developed and the fluid and flow rate meet certain other conditions.

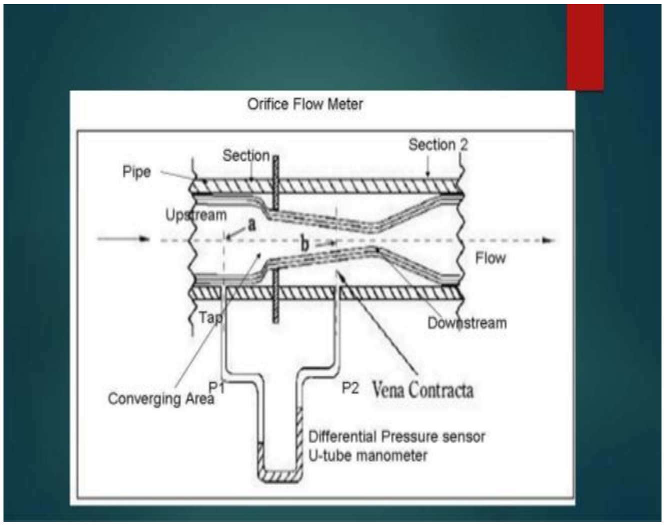


FIGURE 5. Orifice Meter

Under these circumstances and when the orifice plate is constructed and installed according to appropriate standards, the flow rate can easily be determined using published formulae based on substantial research and published in industry, national and international standards. Plates are commonly made with sharp-edged circular orifices and installed concentric with the pipe and with pressure tapings at one of three standard pairs of distances upstream and downstream of the plate these types are covered by ISO 5167 and other major standards. There are many other possibilities. The edges may be rounded or conical, the plate may have an orifice the same size as the pipe except for a segment at top or bottom which is obstructed, the orifice may be installed eccentric to the pipe, and the pressure tapping's may be at other positions. Variations on these possibilities are covered in various standards and handbooks. Each combination gives rise to different coefficients of discharge which can be predicted so long as various conditions are met, conditions which differ from one type to another. Once the orifice plate is designed and installed, the flow rate can often be indicated with an acceptably low uncertainty simply by taking the square root of the differential pressure across the orifice's pressure tappings and applying an appropriate constant. Even compressible flows of gases that vary in pressure and temperature may be measured with acceptable uncertainty by merely taking the square roots of the absolute pressure and/or temperature, depending on the purpose of the measurement and the costs of ancillary instrumentation. Orifice plates are also used to reduce pressure or restrict flow, in which case they are often called restriction plates. *U-tube Manometer:* A 'manometer' is an instrument that uses a column of liquid to measure pressure, although the term is often used nowadays to mean any pressure measuring instrument. By using Bernoulli's principle and the derived pressure head equation, liquids can be used for instrumentation where gravity is present. Liquid column gauges consist of a vertical column of liquid in a tube that has ends which are exposed to different pressures. The column will rise or fall until its weight (a force applied due to gravity) is in equilibrium with the pressure differential between the two ends of the tube (a force applied due to fluid pressure). A very simple version is a U-shaped tube half-full of liquid, one side of which is connected to the region of interest while the reference pressure (which might be the atmospheric pressure or a vacuum) is applied to the other. The difference in liquid level represents the applied pressure.

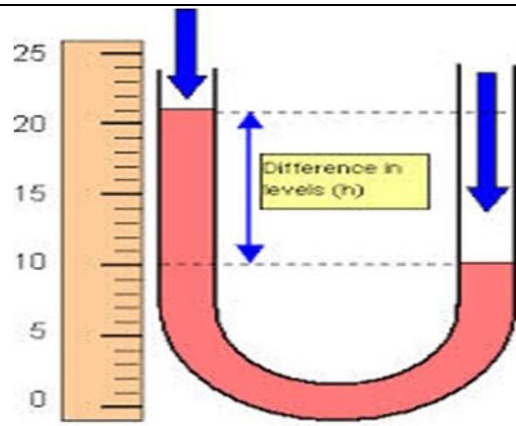


FIGURE 6. U-Tube Manometer

Experimental Procedure: The main objective of this project is to heat the ambient air to a higher temperature using a Solar Air Heater (SAH). Though many models of SAH have already been proposed, this project aims at improving the existing SAH to deliver higher temperature air than the existing models. This is ensured by the following.

- Increasing the heat transfer area of the collector plate using double pass technique with fins on both sides.
- Improving absorption characteristics of SAH using polyester coating.
- Fabrication a setup and experimentally verifying the performance improvement attained under different mass flow rate of inlet air.

5. PERFORMANCE ANALYSIS AND CALCULATIONS

Different types of experiments were conducted to analyze and determine the performance of the Solar Air Heater.

To study the effect of mass flow rate by
- Observing the outlet air temperature
- Computing the efficiency of collector

The experimental analysis involved measuring of the inlet air temperature, collector plate temperature and outlet air temperature sensor and temperature indicator. The mass flow rate of the inlet air is measured by using an orifice meter connected to a manometer. The difference in the mano metric head is directly used to measure the discharge of the blower. Discharge from the blower is obtained from the following expression:

$$Q = \frac{a_0 a_1}{\sqrt{{a_1}^2 - {a_0}^2}} \sqrt{2gh}$$

Where

Q = Discharge from the blower……..m^3/s

C_d = Coefficient of discharge 0.63

a_0 = Area of the Orifice…….. m^2

a_1 = Area of the pipe……… m^2

g = Gravitational force……..m/s^2

h = Mano metric head difference……. m

From the value of Q, mass flow rate is computed using the expression.

$$\mathbf{m = \rho_a \times Q \times 3600} \text{.....Kg/hr}$$

Where

m = Mass flow rate of air…….kg/hr

ρ_a = Density of air…….1.092 kg/m^3

ρ_w = Density of water…1000 kg/m^3

Q = Discharge from the blower ……..$m^{3/}$s

The efficiency of the collector was calculated using the following expression:

$$\eta = \frac{mCp(To-Ti)}{IAc}$$

Where

η = Efficiency of the collector plate

m = Mass flow rate of air…..kg/hr

C_p = Specific heat of air…..kj/kg-k

T_o = outlet temperature of air……Kelvin

T_i = inlet temperature of air …..Kelvin

I = Solar radiation intensity…..w/m^2

A_c = Area of the collector plate…..m^2

6. CALCULATIONS

d_0 = Diameter of the Orifice throat

d_0 = 2.4 cm

a_0 = Area of the Orifice throat = $\frac{\Pi}{4}(d_0)^2$

$a_0 = \frac{\Pi}{4}(2.4)^2$

a_0 = 4.52 cm^2

d_1 = Diameter of the pipe

d_1 = 4 cm

a_1 = Area of the pipe = $\frac{\Pi}{4}(d_1)^2$

$a_1 = \frac{\Pi}{4}(4)^2$

a_1 = 12.56 cm^2

Manometric head difference

(1) Minimum efficiency

$$h = x\left[\frac{specific\ gravity\ of\ water}{specific\ gravity\ of\ air} - 1\right]$$

Where

h = head difference

x = manometer reading

$$h = 6\left[\frac{1000}{1.092} - 1\right]$$

h = 5488.5 cm of water

Then discharge from the blower

$$Q = \frac{a_0 a_1}{\sqrt{{a_1}^2 - {a_0}^2}}\sqrt{2gh}$$

Where

Q = Discharge from the blower….. M^3/s

C_d = Coefficient of Discharge = 0.63

a_0 = Area of the Orifice throat = 4.52 cm^2

a_1 = Area of the pipe = 12.56 cm^2

h = head difference = 5488.5 cm of water

$Q = 0.63 \times \frac{12.56\times4.52}{\sqrt{(12.56^2)-(4.52^2)}} \times \sqrt{2\times981\times5488.5}$

Q=10015.508 cm^3/s

Q=0.010016 m^3/s

Mass flow rate of air m = $\rho_a \times Q \times 3600$…..Kg/hr

Where

M = Mass flow rate of air in kg/hr

ρ_a = Density of Air = 1.092 kg/m^3

Q = Discharge from the blower

Then,

m = 1.092× 0.010016

m = 0.01094 kg/s

m=39.37 kg/hr

Finally Efficiency,

$$\eta = \frac{mCp(To-Ti)}{IAc}$$

Where

η = Efficiency of the collector plate

m = Mass flow rate of air…..kg/hr

c_p= Specific heat of air = 1.005 kj/kg-k =1005w/kg- k

T_o = Outlet air temperature in Kelvin

T_i = Inlet air temperature in Kelvin

I = Solar radiation intensity…..w/m^2

A_c = Area of the collector plate = 0.58× 0.8=0.464 m^2

$\eta = \frac{0.01094\times1.005\times(340-318)}{871\times0.464}$ (23^0 plate inclination 1 pm)

η = 0.6435

η = 64.35

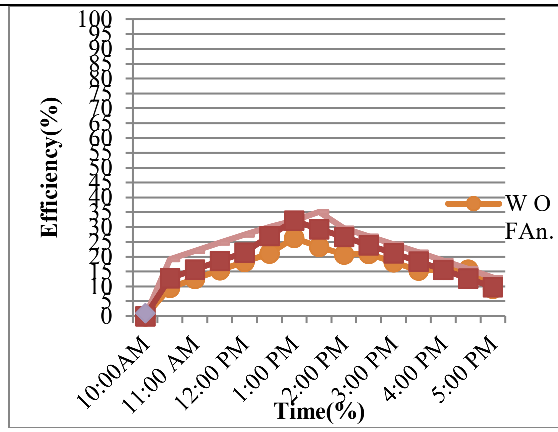


FIGURE 7. Efficiency at an angle 15⁰Vs Time

Variation of Efficiency with time and mass flow rate of 39.37 kg/h without fins, with mild steel fins, with aluminum fins at an angle 15° without fins achieved higher efficiency 26.32 at 1:00PM with mild steel fins achieved higher efficiency 29.25 at 1:30PM and with aluminum fins achieved higher efficiency 35.10% at 1:30PM

.

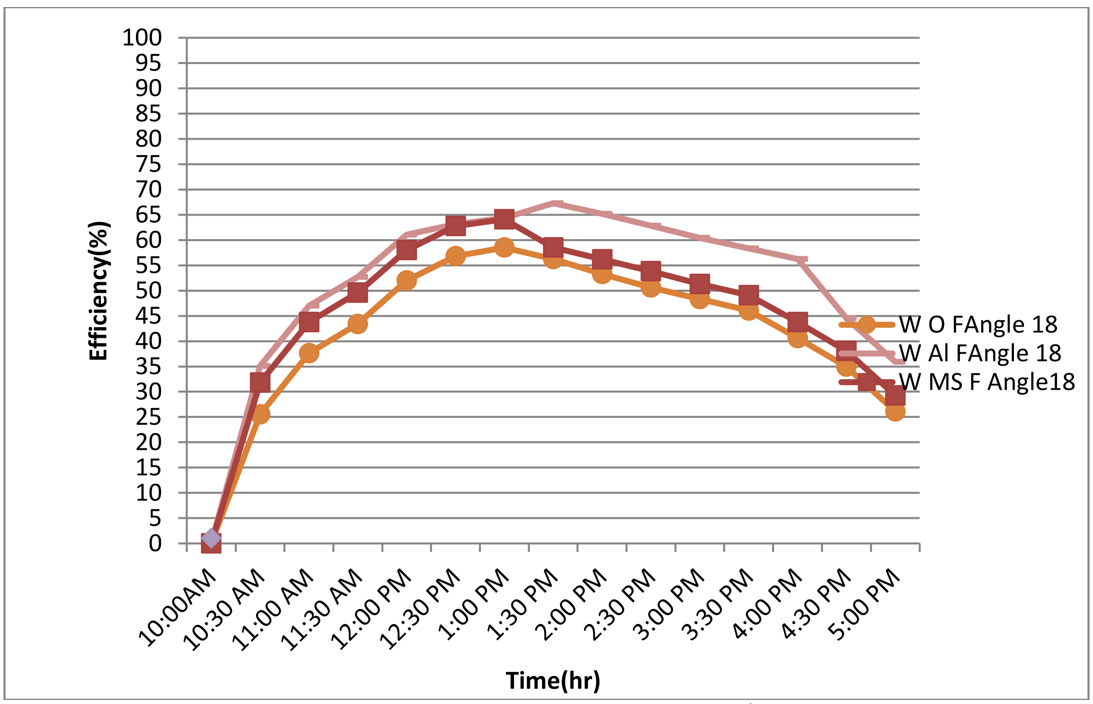


FIGURE 8. Efficiency at an angle 18⁰Vs Time

Variation of Efficiency with time and mass flow rate of 39.37 kg/h without fins, with mild steel fins, with aluminum fins at 18° without fins achieved higher efficiency 58.50 at 1:00PM with mild steel fins achieved higher efficiency 62.80 at 12:30PM and with aluminum fins achieved higher efficiency 67.28% at 1:30PM.

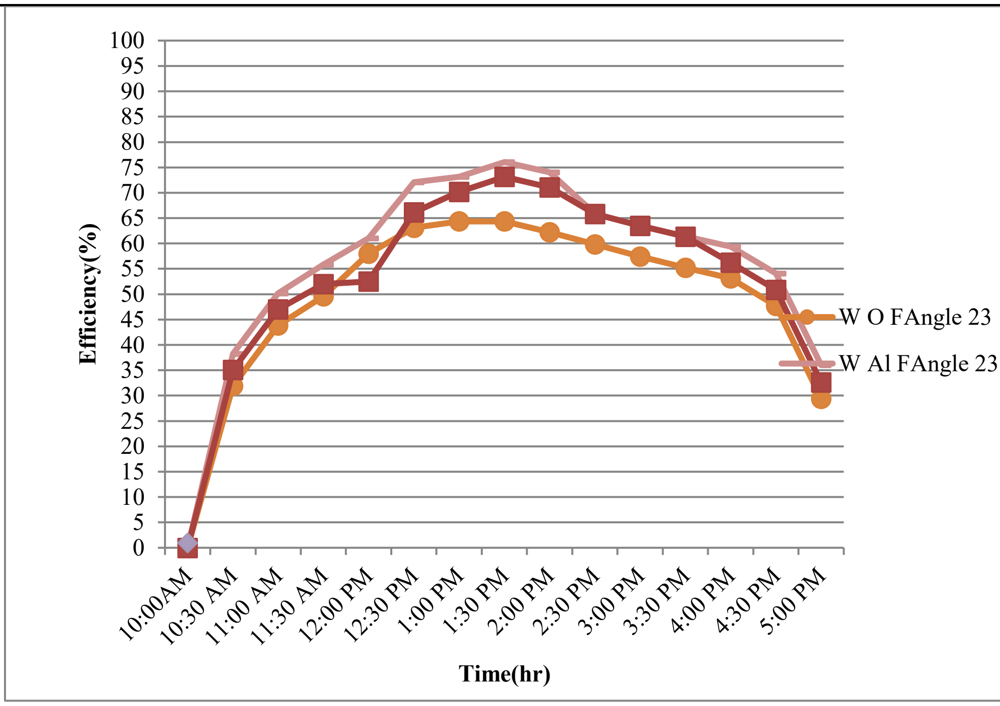


FIGURE 9. Efficiency at an angle 23^0Vs Time

Variation of Efficiency with time and mass flow rate of 39.37 kg/h without fins, with mild steel fins, with aluminum fins at an angle 23^o without fins achieved higher efficiency 64.35% at 1:00PM with mild steel fins achieved higher efficiency 73.13 at 1:30PM and with aluminum fins achieved higher efficiency 76.05% at 1:30PM.

7. CONCLUSION

The experiment will be conducted with 3 types of modification i.e. without fins, with mild steel and aluminum fins with different inclination angles (9^0, 13^0, 15^0, 18^0 and 23^0). Out of our discussions and results the solar collector was gives higher efficiency with aluminum fins when compared with other modifications like without fins and with mild steel fins at different inclination angles. Why because aluminum material having high thermal conductivity and high thermal diffusivity when compared with mild steel fins. The higher efficiency (76.05%) of solar collector with aluminum fins was at 23^0 at 1:30 PM in summer conditions.
So finally out of all results solar collector with aluminum fins will give well results and it is preferable for solar air heaters.

REFERENCES

[1] Akpinar E.K. and Kocyigit F.(2010) "Energy and Exergy analysis of a new flat-plate solar air heater having different obstacles on absorber plates", Applied Energy Vol.87, pp.3438-3450
[2] Ammari H.D. (2003) "A mathematical model of thermal performance of a solar air heater with slats", Renewable Energy Vol.28, pp.1597-1615
[3] Bhagoria. J.L., Saini J.S. and Solanki S.C (2002) "Heat transfer coefficient and friction factor correlation for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate", Renewable Energy Vol.25, pp.341-369.
[4] Chaube A. (2006) "Analysis of heat transfer augmentation and flow characteristics due to rib roughness over absorber plate of a solar air heater", Renewable Energy Vol.31, pp.317-331.
[5] Deniz Alta, EminBilgili, Ertekin C. and Osman yaldiz. (2010) "Experimeantal investigation of three different solar air heaters: Energy and Exergy analyses", Applied Energy Vol.87, pp.2953-2973.
[6] EL-Sebaii A.A. (2011) "Thermal performance investigation of double pass-finned plate solar air heater", Applied Energy Vol.88, pp.1727-1739.
[7] Esen. H (2008) "Experimental energy and exergy analysis of a double-flow solar air heater having different obstacles on absorber plates", Building and Environment Vol.43, pp.1046-1054.
[8] Gupta M.K. and Kaushik S.C. (2009) "Performance evaluation of solar air heater for various artificial roughness geometries based on energy, efficient and exergy efficiencies" Renewable Energy Vol.34, pp.465-476.
[9] Ho C.D., Yeh H.M., Cheng T.W., Chen T.C. and Wang R.C. (2009) "The influences of recycle on performance of baffled double-

pass flat-plate solar air heaters with internal fins attached", Applied Energy Vol.86, pp.1470-1478.
[10] Ho-Ming Yeh and Chii-Dong Ho (2009) "solar air heaters with external recycle", Applied Thermal Engineering Vol.29, pp.1694-1701.
[11] Ozgen. F (2009) "Experimental investigation of thermal performance of a double-flow solar air heater having aluminum cans", Renewable Energy Vol.34, pp.2391-2398.
[12] Omojaro .A.P. (2010) "Experimental performance of single and double pass solar air heater with fins and steel wire mesh as absorber", Applied Energy Vol.87, pp.3759-3765.
[13] PaisanNaphon (2005) "On the performance and entropy generation of the double –pass sola air heater with longitudinal fins", Renewable Energy Vol.30, pp.1345-1357.
[14] Rakesh Kumar and Marc A. Rosen (2011) "Performance evaluation of a double pass PV/T solar air heater with and without fins", Applied Thermal Engineering Vol.31, pp.1402-1410.
[15] Rodriguez-Hidalgo M.C. Rodriguez-Aumente P.A., Lecuona A., Gutierrez-Urueta G.L. and Ventas R.(2011)"Flat plate thermal solar collector efficiency: Transient behavior under working conditions. Part I: Model description and experimental validation", Applied Thermal Engineering Vol.31, pp.2394-2404.
[16] SoterisKalogirou (2003) "The potential of solar industrial process heat applications", Applied Energy Vol.76, pp.337-361.
[17] Wazed M.A. Nukman Y., and Islam M.T. (2010) "Design and fabrication of a cost effective solar air heater for Bangladesh", Applied Energy Vol.87, pp.3030-3036.

