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Original Article

Experimental Study of Solar Air Heater Equipped with Longitudinal Fins aiming Thermal Performance Improvement

Birendra Kumar[1], Ashutosh Kumar[2], Shailesh Ranjan Kumar[3], Ravi Kumar[4], Chandra Shekhar Singh Chandal[5], Saket Kumar Singh[6], Manoj Kumar[7]

[1,2,3,4]*Department of Mechanical Engineering, Motihari College of Engineering Motihari, Bihar, India*
[5,6]*Department of Electrical & Electronics Engineering, Motihari College of Engineering Motihari, Bihar, India*
[7]*Department of Mechanical Engineering, Gaya College of Engineering Gaya, Bihar, India*

[1]*Corresponding Author : birendra.2013dr0236@mech.iitism.ac.in*

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Abstract - *For environments with mild to moderate temperatures, a solar air heater is a viable option. Home heating, agricultural drying, timber seasoning, and other commercial uses are all possible with a solar air heater. An investigation of the thermal efficiency of a solar air heater is carried out in this experiment. Inside the absorber plate, long, thin fins were added to increase the rate at which heat could be transferred. Fins were designed to be square. The fin had a pitch of 1 and 2 inches. Two varying rates of fluid mass flow of 0.00452 kg/s and 0.0014 kg/s with two different Reynolds numbers, 4577.46 and 10285.55, were used in the experiment. In this experiment, the investigation is focused on getting an insight into how changes in the rate of flow of air affected the solar collector's outlet temperature, heat transfer through its thickness, and overall thermal efficiency. In comparison to collectors without fins, it was discovered that those with fins increased the temperature of outflow air, efficiency of collectors, and heat transfer performance.*

Keywords - *Solar air heater, Fin, Thermal efficiency, Reynolds number, Nusselt number.*

Nomenclature

$\mathring{m}$	A mass flow rate of the air, kg/s
A	Area of inlet cross section, m^2
V	The velocity of inlet air, m/s
$A_{.C.}$	Area of the absorber plate, m^2
L	Length of the absorber plate, m
B	Width of the absorber plate, m
Z	Depth of solar air heater, m
$C_{.P.}$	Specific heat of air, J/kg K
Δ_T	A temperature rise in the air
I	Solar intensity, W/m^2
De	Characteristics length, m
$L_{.S.}$	Space between absorber plate and bottom plate, m
W	Distance between two consecutive fins, m
L_f	Height of fin, m
Nu	Nusselt number
Re	Reynolds number
f	Friction factor
Pr	Prandtl number
Δp	Pressure drop, N/m^2
t	Thickness, m
θ	Tilt angle
T_{mean}	The mean temperature of the absorber plate, ⁰C
Ti	The inlet temperature of the air, ⁰C
To	The outlet temperature of the absorber plate, ⁰C
Greek symbols	
ρ	The density of air, kg/m^3
δ	The thickness of the fin, m
η	Thermal efficiency of the heater, %
μ	Dynamic viscosity, N-s/m^2

1. Introduction

India's power supply has improved and expanded in recent years, but the country still faces frequent and severe energy and peak-load shortages. The issue is larger than just the lack of electricity. The proliferation of it is a problem in its own right. Once upon a time, when deciding on an energy source for heating air, the major concern was the lowest cost and most availability. A solar air heater is an efficient tool for converting solar heat into usable heat. Solar air heaters are practical in areas where the weather is generally mild. Solar air heaters have a varied range of potential tenders, such as residential heating, agricultural drying, timber seasoning, and commercial applications.

Adding fins to the collector, switching up the absorber's materials, and adjusting the number of flow channels is all ways to boost the effectiveness of a solar air heater. Reportedly, solar air heaters that have fins connected to them perform far better than those that do not have fins attached to them, according to research [1] that was conducted. Solar air heaters with two streams are found to be more efficient than those with a single stream [2], and a double-acting collector is proven to be more effective than single-flowing solar air heaters [3,4]. In laboratory tests, a solar air heater with punctured barriers on the inlet air edge of the absorber plate was shown to produce much higher temperatures. [5]. the results showed a 22-33% increase in thermal efficiency compared to a solar air heater with a smooth duct. When the flow of the mass rates rises, a solar air heater with longitudinal fins increases efficiency by about 5 % [6,7]. After 50 minutes of sun exposure with solar irradiation ranging from 900 to 1000 W/m2, solar air collectors with baffles and a double air channel may achieve an efficiency of more than 50% [8]. It may be accomplished using solar irradiation.

When attempting to find the optimum parameters for the number of fins, the position of the fins, and the width of the fins, it is essential to consider the outflow air temperature and the pressure drop as controlling components [9-10]. Conventional solar air heaters have come under scrutiny for the high rates of heat loss that they experience to the environment around them and for the insufficient levels of heat convection that they experience from the absorber plate to the air stream. [11]. Changing the absorber plate configurations of a double-pass solar air heater, such as switching between a flat plate, pin-finned plate, or corrugated finned plate, may significantly impact the device's overall efficiency. This could include switching between a plate with a flat surface, plates with pin fins, or plates with corrugated fins. [12]. A solar air heater's thermal performance can be affected in several ways by the fins' shape. In terms of efficiency and mass flow rate, rectangular fins have a minor advantage over triangular and elliptical ones [13-14]. According to [15], the primary factor contributing to a solar air space heater's moderate to poor heat transfer capacity is its co-efficient convective heat transfer rating between the absorber plate and the air. One of the most effective methods for improving the efficiency of solar air heaters is to give them an artificial roughness that's also formed in the form of repetitive ribs. It was determined that the optimal combination of the number of glazing covers and the spacing between the glazing covers (air gap) resulted in the least amount of top heat loss. They achieved this by comparing single, double, and triple-glazed black-painted flat plate collectors with varying amounts of air space in between the glass panes of each kind of collector. Each type of collection had a single, double, or triple-glazed black-painted flat plate collector. This objective was accomplished by conducting three distinct trials, each with a "one component at a time" design, on single-, double-, and triple-glazed FPCs. In these investigations, the amount of space that existed between the panes of glass was treated as a variable component that may take on one of three distinct forms [16].

Despite the potential of a solar air heater having the form of a flat plate with fins running in longitudinal directions, the available literature suggests that little research and development work has been done on this front. It set out to examine how changing factors like mass flow rate and Reynolds number affected the efficiency of a flat-plate solar air heater operating under the same conditions. New fin designs are needed to improve the efficiency of solar air collectors. This paper aims to look into how one that uses fins and one that does not inside the duct responds to changes in flow and geometric characteristics.

This experimental study's objective is to improve the overall efficiency of a solar system-based air heater that has been fitted with longitudinal fins. Creating a single-pass, counter-flow solar air collector equipped with longitudinal fins is the principal focus of the inquiry that is now being carried out. It aims to increase the solar collector's thermal efficiency. In this study, a solar air collector was tested based on its capacity to heat air via longitudinal fins and its total area for the purpose of facilitating heat transfer. The experimental results of a comparison between a solar air collector with and without fins for usage in a single pass are presented in this paper. This paper analyses the efficiency of a heater generated by the sun both with and without their characteristic longitudinal fins, taking into account the effects of different air mass flow rates, varying sun intensities, and flow characteristics like numbers representing the Reynolds number, the Nusselt number, and the friction factor

2. Experimental Methodology

These same error terms have been computed utilizing a technique developed by Kline and McClintock [17]. Table 1 displays the precision of the equipment used to estimate the error. Quasi-variable Re, Nu, and friction factor maximum uncertainties are 4%, 3%, and 6%, including both.

The mass flow rate of air is expressed as
$m = \rho AV$

The area of the absorber plate is
$A_c = L \times B$

The effectiveness of heat transfer

$$\eta = \frac{mC_p\Delta T}{IA_c}$$

The bulk mean temperature of the absorber plate is expressed as
Characteristics length
(a) Without longitudinal fins

$$D_e = \frac{4LL_s}{2(L + L_s)}$$

(b) With longitudinal fins

$$D_e = \frac{4(WL - \delta_f L_f)}{2(W + L_f)}$$

The Nusselt number is estimated by using the equation.
(a) Without longitudinal fins
$Nu = 0.0158\ Re^{0.8}$

(b) With longitudinal fins
$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$
The Reynolds number is given as

$$Re = \frac{\rho V D_e}{\mu}$$

The coefficient of friction, denoted by f, may be expressed as
(a) Without longitudinal fins

$$f = 0.079\ Re^{-0.25}$$

(b) With longitudinal fins

$$f = M\ Re^{-m}$$

Where, $M = 0.040\ [2.058 - \{(L - L_f)/L_f\}^{0.313}]$ for $Re < 15000$
$= 0.033\ [1.394 - \{(L - L_f)/L_f\}^{0.408}]$ for $Re > 15000$
$m = 0.075\ [3.40 - \{(L - L_f)/L_f\}^{0.711}]$ for $Re < 15000$
$= 0.138\ [1.435 - \{(L - L_f)/L_f\}^{0.773}]$ for $Re > 15000$
Pressure drop can be expressed as

$$\Delta p = \frac{4f\rho L}{2D} V^2$$

Table 1. Precision of the equipment that was utilized.

Sl.No.	Equipment	Precision
1.	Hot wire Anemometer (AVM-08)	Velocity = ±(5%+1d) reading, temperature = ±1˚C/1.8˚F
2.	Digital Temperature Indicator	± 1% of FSD
3.	j- type Thermocouple	± 2̊ C

3. Detailed explanation of innovative methodology and Design

Arrangements for conducting experiments are shown in Figure 1, and a geometric cross-sectional image of the setup, highlighting the pattern of air movement in the ducts, is shown in Figures 2 and 3. A number of absorber plates that have been given a dark coating and a blower are included in its construction. With or without longitudinal fins, plywood casing, glass cover plate, solar power meter, digital hot wire anemometer (DHWA), digital temperature indicator (DTI), J-type thermocouple mounted at inlet & outlet duct as well as on absorber plate at three points. Plywood is used as an insulating material for the casing of the air heater. A movable metal platform inclined at a specified degree holds the whole assembly aloft so it can be seen from above. The geometrical terms of the table display the solar air heater in its many forms. The rate of air that is being taken in as measured in terms of mass flow $\mathring{m}_1$ is supplied by the blower with a circular inlet channel. An electronic hot wire instrument is used to measure the airflow velocities at both the intake and outflow (DHWA). The accuracy of DHWA is ± 0.1 m/s (in velocity) and 1^o C (temperature) with the operating temperature range is 0^o C to 50 ^{0}C. The J-type thermocouple having accuracy ± 2 ^{0}C and a range of operating temperature (−40 ^{0}C to +750 ^{0}C), is used for measuring the inlet and outlet temperature of the air. The temperature measured by the thermometer is displayed on the temperature sensor meter (DTH). A total of five thermocouples are used in the whole setup. However, three are embedded in the absorber plate. The solar intensity (I) was recorded during the experiments using a solar power meter. The angle of inclination, denoted by the symbol, of the solar air heater has been described in relation to the plane of the flat plane. At the Motihari College of Engineering, Motihari, an experiment on a flat-plate solar air warmer has been carried out located at latitude 26.6438º N and longitude 84.9040º E with an elevation of 203.41 feet (62 m) above sea level. For calculating the performance of the solar air heater, some variables have been examined and controlled, such as mass flow rates of air and $\mathring{m}1$ through the flow channel. The other variables are examined, namely, solar intensity, wind velocity, temperatures at the air's intake and output, and atmospheric and plate temperatures. The following instruments, with their accuracy (shown in Table 4), are used for controlling and recording the above variables.

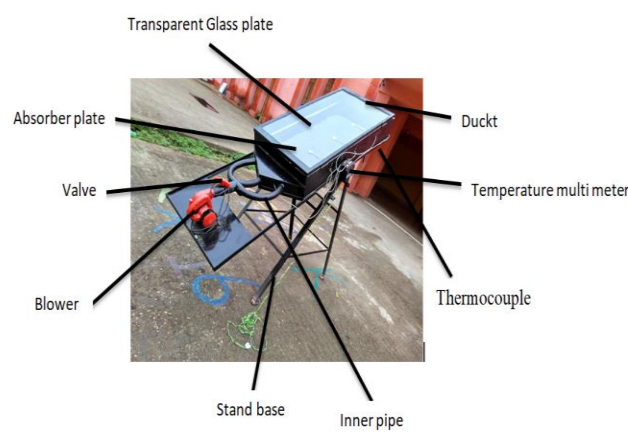

Fig. 1 Evidence in the form of photographs of the instrumentation test apparatus

Fig. 2 Documenting via photography of the fins and without fins

Table 2. Geometrical specification of the setup

S. No.	Nomenclature	Specifications
1.	Length of collector	L = 1.176 m
2.	Width of collector	B = 0.5689 m
3.	The thickness of the absorber plate	t = 0.81 mm
4.	The thickness of the glass cover	t = 3.5 mm
5.	Length of fins	1.143 m
6.	Height of fins	Lf = 6.35 cm
7.	Thickness of fins	δ= 0.81 mm
8.	Number of fins	N_f = 30
9.	Tilt angle	α= 60⁰
10.	Base and side insulation	t = 16 mm
11.	Thermal conductivity of fins and absorber plate(mild steel)	45.3 W/m.K

Table 3. Instruments used with their accuracy

S. No.	Name of the instruments	Accuracy
1.	Digital Hot Wire Anemometer	± 0.1 m/s (in velocity) 1 ^{0}C (in temperature)
2.	Solar Power Meter	Within ± 10 W/m^2 or ± 5 %
3.	Thermocouples	± 2 ^{0}C
4.	Digital Temperature Indicator	± 1 % of full-scale deflection

Fig. 3 A digital hot wire anemometer

Fig. 4 A Solar Power Meter

Fig. 5 J-Type Thermocouple

Fig. 6 Solar Power Meter

In the present work, a calibrated DHWA; Model HTC AVM-08 (Ranges: 0.1 – 25 m/s and 0 ⁰C to 50 ⁰C) has been used for measuring the wind velocity, the temperature at the beginning and end of the channel, as well as the speed at which the air is moving as it travels through the channel. The photographic view of the digital hot wire anemometer (DHWA) is shown in Fig.3

The solar intensity has been measured by the CEM DT-1307 Solar Power meter, which is shown in Fig. 6. It has a range of 1999 W/m^2. It consists of a hemispherical-shaped magnetic mount sensor made up of high sensitivity silicon diode, which senses the beam and diffused radiation and delivers the value in a backlit LCD display. It is operated with 4.5 V batteries. It is quite simple to use and handle.

The local temperature of the absorber plate at three points is measured by a J-type thermocouple (Range: -40 ⁰C to +750 ⁰C), which is shown in Fig. 5. It has a high sensitivity of about 50 µV/°C. It is very fragile with reliability and life performance.

The Multispan digital temperature indicator (DTI), having an LED display for Fig. 4, depicts a solar air warmer in operation. The total five thermocouples are plugged in with DTI to display the measurements taken from the absorber plate and the air temperature. The operating temperature is from 0 ⁰C to 55 ⁰C. It can be widely used for J-type, K-type, and PT-100. The accuracy is ± 1 % of full-scale deflection.

4. Result and Discussion

4.1. Temperature Gain or Loss Due to Air Flow Rate in Solar Concentrator

Figure 7 is a representation of how the thermal effectiveness of the solar air heater is affected by the air mass flow rate. When there is a greater mass movement rate, there is a correspondingly greater rise in the heating value. The highest heat efficiency of an absorber plate without a fin is 55.48, present with a mass movement rate of 0.0096 kg/s. In an absorber plate with a longitudinal fin of pitch length 1 inch, thermal efficiency is 65.41% with a mass movement rate of 0.0101 kg/s. By increasing the number of longitudinal fins in the same absorber plate, it has been found that the effectiveness of heat transfer is 70.11 at the mass movement rate of 0.0108 kg/s. Here, the geometry of the absorber plate and mass movement rate crucially affect the thermal efficiency; higher airflow rate increases result in greater air convection, which increases the heater’s heating value. It has been revealed that the heat source with fins is currently more effective than that of the solar collector that does not have fins. The pitch length also acquires a prominent role in affecting performance. It is clear that the heating value plays an important role. It is the highest finned absorber plate with a pitch length of 1 inch, followed by a plate with a pitch length of 2 inches.

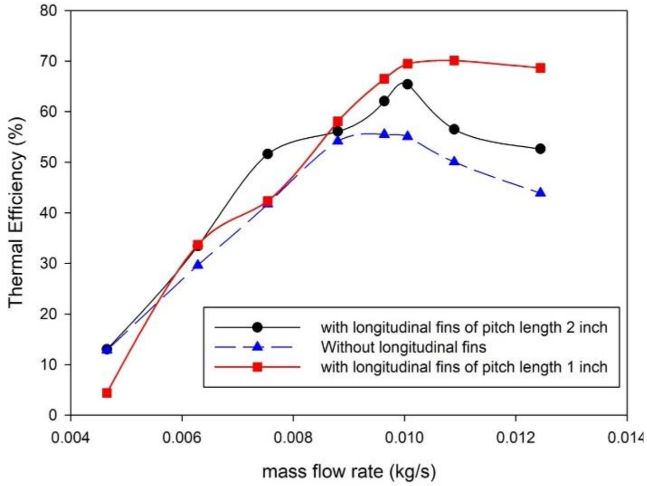

Fig. 7 shows how the thermal efficiency varies depending on the mass flow rate of air, with or without longitudinal fins, and at varying pitch lengths.

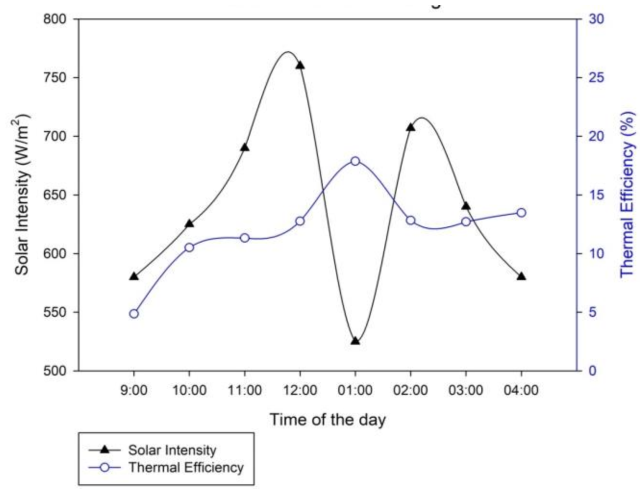

Fig. 9 Shows how an absorber plate's thermal efficiency and solar intensity change over time. The plate has longitudinal fins with a pitch length of 1 inch, and the plate's mass flow rate is 0.00465 kg/s.

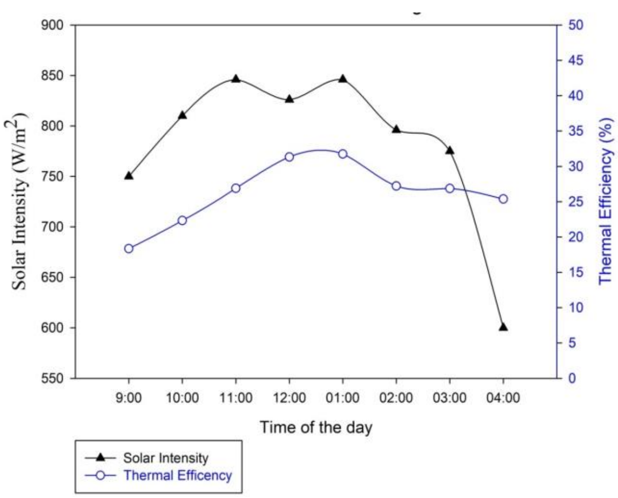

Fig. 8 Variation of thermal efficiency and solar radiation with time in absorber plate without longitudinal fin at the mass flow rate of 0.0045 kg/s

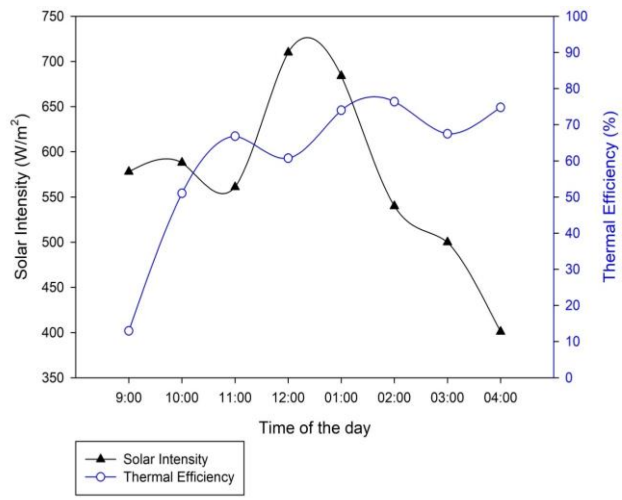

Fig. 10 shows how the thermal efficiency and sun intensity change over the course of one hour in an absorber plate with a pitch length of one inch and a mass flow rate of 0.01248 kg/s.

Figures 8 and 9 show the effect of the amount of solar radiation on an absorber plate's thermal efficiency over time while the plate runs at two different mass flow rates. The absorber plate does not contain a longitudinal fin. The maximum degree of thermal efficiency that was discovered to be feasible was 31.74%, and it could be achieved with a mass flow rate of 0.00465 kg/s with an intensity of 846 W/m2 from the sun. It obtained the greatest achievable efficiency of 63.90% by increasing the mass flow rate to 0.01248 kg/s, resulting in an intensity of 968 W/m2 for the system. The intensity of 968 W/m2 is used in the most efficient model of solar air heaters, making this value the most that can be attained. Figure 10 displays the performance of an absorber plate with a longitudinal fin having a pitch length of one inch while operating at a mass flow rate of either 0.00465 or 0.01248 kilograms per second.

The pitch length of the fin is measured in inches. Because of the gloomy weather and the flow rate of mass of 0.00465 kg/s, the efficiency level that has been able to accomplish its greatest potential is 17%. This was the highest degree of efficiency that could possibly be obtained. It was determined that 525 W/m2 was the greatest amount of intensity that could be seen. The thermal efficiency was able to reach 76.43% when the intensity was set at 540 watts per square meter, and the mass flow velocity was set at 0.01248 kilograms per second. The variation in thermal efficiency and insolation is shown in Figures 12 and 13, which illustrate an absorber plate with a pitch length of 2 inches and mass flow rates of 0.01248 and 0.00465 kg/s, respectively. With maximum insolation of 750 W/m^2, the maximum thermal efficiency obtained is 67.43 % having a mass flow rate of 0.01248, and 31.74 % of thermal efficiency is attained with a maximum intensity of 836 W/m^2 having a mass flow rate of 0.00465 kg/s.

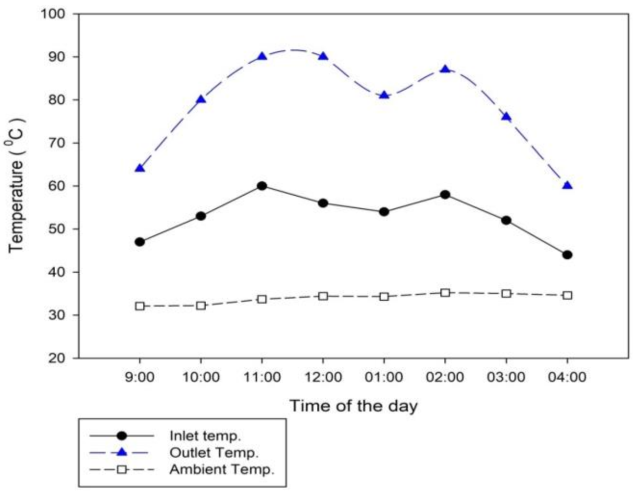

Fig. 11 Shows the changes in temperature at the outlet, the inlet, and the ambient temperature over the course of an hour in an absorber flat with no fins and a mass flow of 0.00465 kg/s.

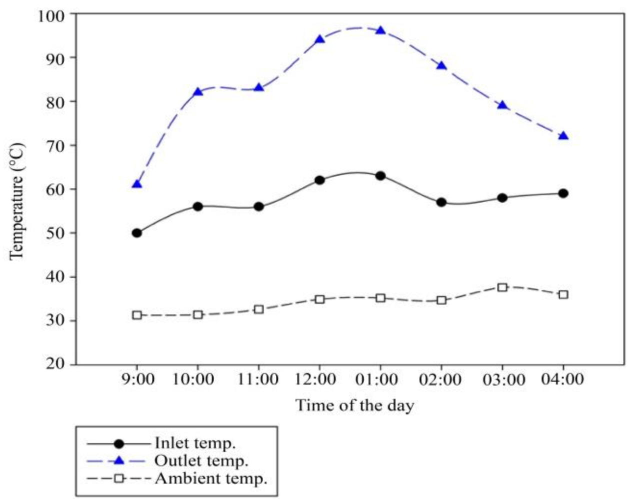

Fig. 12 Shows the changes in temperature at the outlet, the inlet, and the ambient temperature over the course of time in an absorber flat with no fins and a mass flow of 0.01248 kg/s.

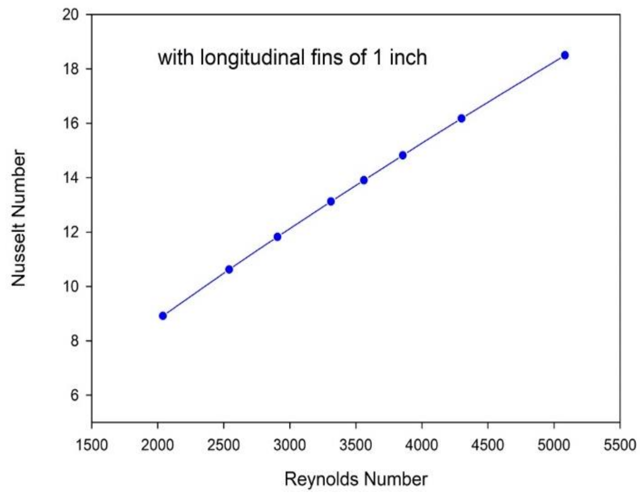

Fig.13 The plot of the Nusselt number against the varying Reynolds numbers

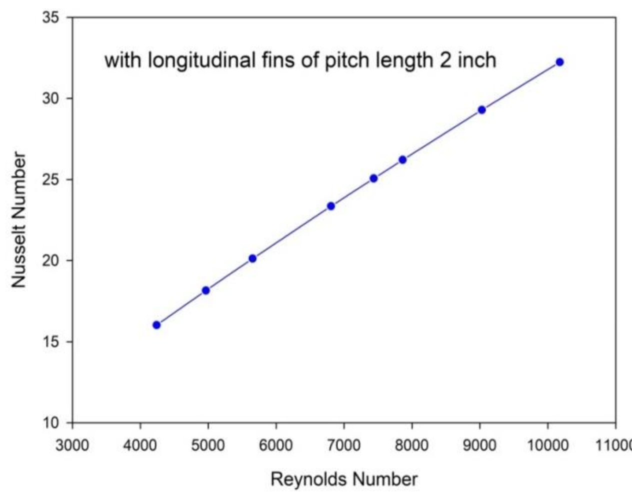

Fig.14 The plot of the Nusselt number against the varying Reynolds numbers

The average solar intensity varies from 500-1000 W/m^2during the whole experiment. Fig. 11 illustrates the fluctuation in temperature experienced by the air as it travels across the absorber plate without even a fin. It is clear from looking at both figs that now the temperatures reach an almost all-time high just around noon. With such a peak solar irradiance of up to 0.01248 kg/s, both the outflow and the input have the same temperature. Temperature increases simultaneously. Figures 13–15 illustrate the range of temperatures experienced by an absorber plate, including a longitudinal fin with a pitch length of one inch. It is possible to observe that the mass flow rate and the intensity have an effect on all of the temperatures under each scenario. Figures 12, 13, and 14 illustrate the fluctuation of the Nusselt number with regard to the Reynolds number with longitudinal fins with pitch lengths of 1 and 2 inches, respectively, and without fins.

Figures 15, 16, and 17 show the connection between the friction factor and the Reynolds number and its changes when there is no longitudinal fin and when there is a fin with pitch lengths of 2 inches and 1 inch. Improvements in the Reynolds number (Re) are followed by rises in the Nusselt number (Nu) in the pitches lengths of 1 inch and 2 inches, as well as in the situation where there is no pitch length; nevertheless, the Nusselt number (Nu) is greater in the scenario where there is the shortest pitch length. Therefore, a greater Reynolds number (Re) at the lowest pitch length causes a rise in turbulence. As a result of the increase in turbulence, the heat transfer rate through the duct also rises. It has been discovered that the Reynolds number (Re) and the pitch length have a much greater impact on the Nusselt number (Nu) and the friction factor (f) than any of the other variables. The Reynolds number (Re) as well as the Nusselt number both have a negative correlation with the friction factor (f) (Nu).

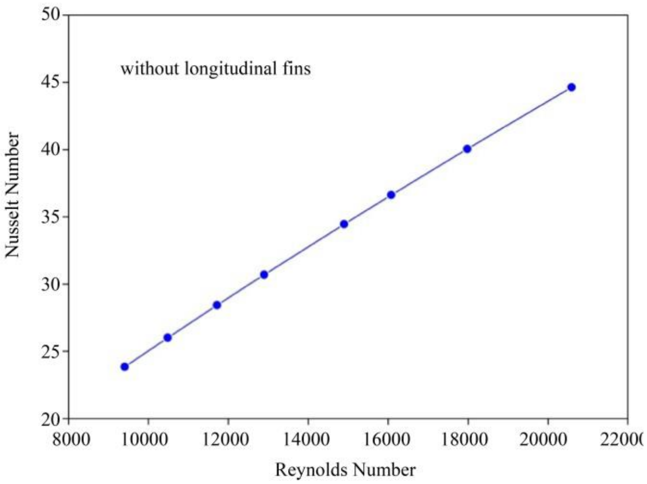

Fig. 15 The plot of the Nusselt number against the varying Reynolds numbers

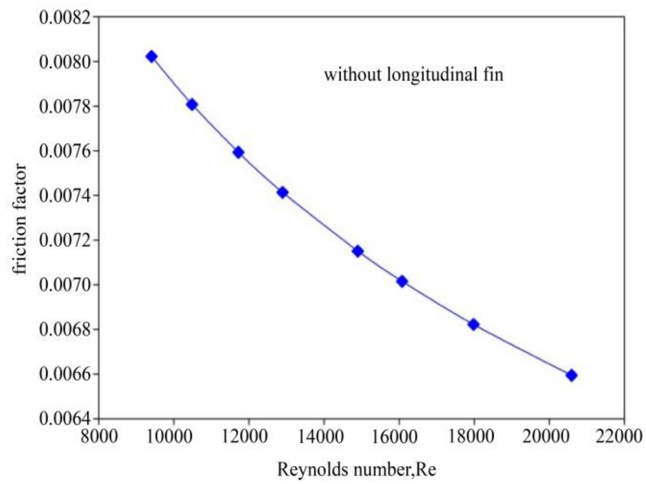

Fig.18 The plot of friction factor against the varying Reynolds numbers

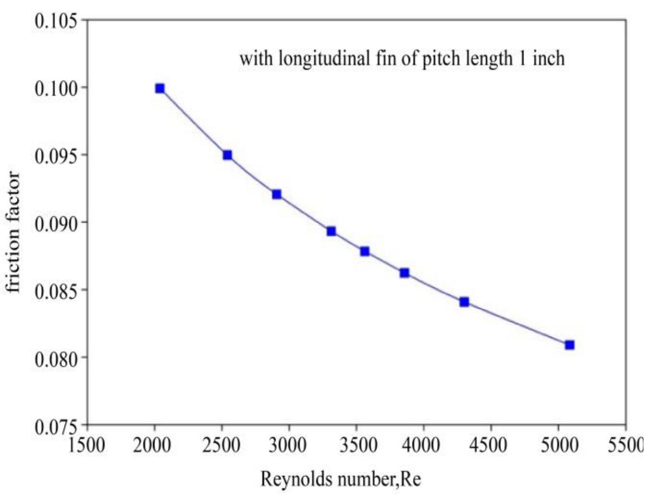

Fig. 16 The plot of friction factor against the varying Reynolds numbers

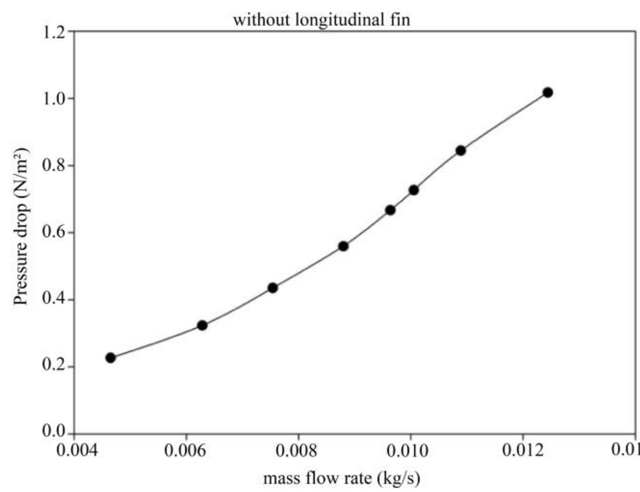

Fig. 19 The plot of the pressure drop against the varying mass flow rate

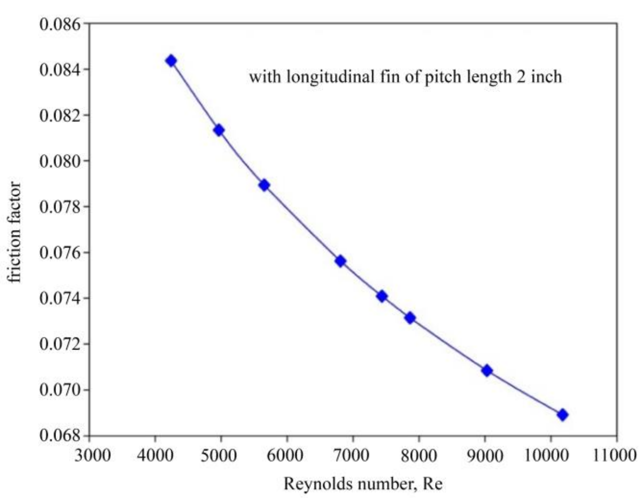

Fig. 17 The plot of friction factor against the varying Reynolds numbers

The friction factor drops higher in the case of minimal pitch length while the Reynolds number (Re) remains the same. Due to the reduced friction factor at the shortest possible pitch length, the efficiency of the solar collector is improved. The variation in pressure drop that takes place in an absorber plate that does not have a longitudinal fin is seen in Figure 18. There are two versions of this plate, one with a pitch length of 2 inches while the other has a pitch length of 1 inch. This diagram shows how the pressure loss grows in proportion to the mass flow rate. This takes place due to the fact that an increase in the mass flow rate generates a rise in the wind speed, which has, in effect, caused a higher loss of pressure.

5. Conclusion

The outcomes of this investigation allow for the possible inference of the following effects and conclusions.

- The provision of longitudinal fins with varying pitches significantly improved the rate of heat transmission.

- Through the attachment of longitudinal fins, the thermal efficiency has a progressive influence on the mass movement rate, sun intensity, and absorber plate surface area. As a result of reducing the number of pitches, effectiveness may also be improved.
- When it comes to figuring out the temperature of a fluid, the mass movement rates and the coefficients of heat transfer are two of the most crucial aspects to consider.
- The absorber plate that does not have a longitudinal fin produces the biggest increase in Nusselt number, followed by that of the fin with a pitch length of 2 inches and 1 inch, respectively.
- While the fins were attached to the bottom of the absorber surface, there was a negligible shift in the friction factor.
- The decrease in pressure is proportional to the rise in the mass flow rates.

References

[1] A.P. Omojaro, and L.B.Y. Aldabbagh, "Experimental Performance of Single and Double Pass Solar Air Heater with Fins and Steel Wire Mesh as an Absorber," *Applied Energy,* vol. 87, no. 12, pp. 3759–3765, 2010. *Crossref,* https://doi.org/10.1016/j.apenergy.2010.06.020

[2] Paisarn Naphon, "On the Performance and Entropy Generation of the Double-Pass Solar Air Heater with Longitudinal Fins," *Renew Energy,* vol. 30, no. 9, pp. 1345–1357, 2005. *Crossref,* https://doi.org/10.1016/j.renene.2004.10.014

[3] Nwachukwu P. Nwosu, "Employing Exergy-Optimized Pin Fins in the Design of an Absorber in a Solar Air Heater," *Energy,* vol. 35, no. 2, pp. 571-575, 2010. *Crossref,* https://doi.org/10.1016/j.energy.2009.10.027

[4] Mr.Arunprasad S, Dr.Saravanan P, and Mr.Arulraj R, "Design and Analysis of Flat Plate Solar Air Collector," *SSRG International Journal of Mechanical Engineering,* vol. 7, no. 5, pp. 14-19, 2020. *Crossref,* https://doi.org/10.14445/23488360/IJME-V7I5P103

[5] Maheshwari B.K. et al., "Performance Study of Solar Air Heater with Baffled Duct," *IOSR Journal of Mechanical and Civil Engineering*, vol. 4, no. 5, pp. 52-56, 2012.

[6] Chabane Foued, Noureddine Moummi, and Said Benramache, "Experimental Study of Heat Transfer and Thermal Performance with Longitudinal Fins of Solar Air Heater," *Journal of Advanced Research,* vol. 5, no. 2, pp. 183-192, 2014. *Crossref,* https://doi.org/10.1016/j.jare.2013.03.001

[7] Harish Kumar Patel et al., "Thermal Performance of Solar Air Heater by with Artificial Roughness - A Review," *SSRG International Journal of Mechanical Engineering,* vol. 2, no. 4, pp. 14-17, 2015. *Crossref,* https://doi.org/10.14445/23488360/IJME-V2I4P103

[8] Sanda Budea, "Solar Air Collectors for Space Heating and Ventilation Applications Performance and Case Studies Under Romanian Climatic Conditions," *Energies,* vol. 7, pp. 3781-3792, 2014. *Crossref,* https://doi.org/10.3390/En7063781

[9] Veena Pal, Ajeet Kumar Rai, and Vivek Sachan, "Performance Study of a Solar Air Heater," *International Journal of Mechanical Engineering and Technology,* vol. 6, no. 7, pp. 1-7, 2015.

[10] T Bhattacharyya, R Anandalakshmi, and K. Srinivasan, "Heat Transfer Analysis on Finned Plate Air Heating Solar Collector for its Application in Paddy Drying," *Energy Procedia*, vol. 109, pp. 353–360, 2017. *Crossref,* https://doi.org/10.1016/j.egypro.2017.03.086

[11] K. Rajarajeswari, and A. Sreekumar, "Matrix Solar Air Heaters," *Renewable and Sustainable Energy Reviews,* vol. 57, pp. 704–712, 2016. *Crossref,* https://doi.org/10.1016/j.rser.2015.12.127

[12] A. Hachemi, "Experimental Study of Heat Transfer and Flow Friction in Solar Air Heaters with and without Selective Absorbers," *Renewable Energy*, vol. 17, pp. 155-168, 1999. *Crossref,* https://doi.org/10.1016/S0960-1481(98)00114-1

[13] Hamdy Hassan, and Saleh Abo-Elfadl, "Experimental Study on the Performance of Double Pass and Two Inlet Ports Solar Air Heater (SAH) at Different Configurations of the Absorber Plate," *Renewable Energy,* vol. 116, pp. 728-740, 2018. *Crossref,* https://doi.org/10.1016/j.renene.2017.09.047

[14] M.A. Karim, and M.N.A. Hawlader, "Development of Solar Air Collectors for Drying Applications," *Energy Conversion and Management,* vol. 45, pp. 329–344, 2004. *Crossref,* https://doi.org/10.1016/S0196-8904(03)00158-4

[15] Ho-Ming Yeh, "Upward-Type Flat-Plate Solar Air Heaters Attached with Fins and Operated by an Internal Recycling for Improved Performance," *Journal of the Taiwan Institute of Chemical Engineers,* vol. 43, no. 2, pp. 235–240, 2012. *Crossref,* https://doi.org/10.1016/j.jtice.2011.10.008

[16] Jitender Singh Khurana, Dr.Chandresh Sharma, and Ramesh Parihar, "Review of Roughness Enhancement of Solar Air Heaters having Different Rib Roughness Geometries on Absorber Plate," *International Journal of Engineering Trends and Technology*, vol. 58, no. 1, pp. 46-53, 2018. *Crossref,* https://doi.org/10.14445/22315381/IJETT-V58P210

[17] Dhrupad Sarma, Parimal Bakul Barua, and Diganta Hatibaruah, "Optimization of Glazing Cover Parameters of a Solar Flat Plate Collector (FPC)," *International Journal of Engineering Trends and Technology*, vol. 14, no. 2, 2014. *Crossref,* https://doi.org/10.14445/22315381/IJETT-V14P216

[18] S. J. Kline, and F. A. McClintock, "Describing Uncertainties in Single-Sample Experiments," *Mechanical Engineering,* vol. 75, no. 1, pp. 3-8, 1953.

[19] Manish Kumar Singh, Dinesh Kumar, and Ankit Thakur, "Theoretical Investigation of Solar Still Coupled with Solar Air Heater," *SSRG International Journal of Mechanical Engineering,* vol. 2, no. 9, pp. 5-9, 2015. *Crossref,* https://doi.org/10.14445/23488360/IJME-V2I9P102