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A Comparative Analysis of Ribs and Cans Type Solar Air Heater

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Abstract India is a country that has an abundant amount of solar energy. Air Heating is a famous application of solar energy. The heated air can be used in industry in number of application like crop drying, wood seasoning and in refinery. The Solar Air Heater is the device which is used for heating the air with the help of solar energy. In this study, the two designs of solar air heatesr analyzed and compared. The first design consists of triangular fins produced over absorber plate and second one has the tin can pipes fixed over the absorber plate. The comparison of both solar heaters was made based on Heat transfer rate, efficiency, Nusselt number, friction factor and pressure drop. The average enhancement in temperature difference is found 32.77 °C and 30.18 °C in October and 22.64 °C and 20.42 °C in December in Can Solar Air Heater (CSAH) and Ribs Solar Air Heater (RSAH) respectively. In CSAH, the average heat transfer rate is improved by 7.65 % and 10.17% in October and December respectively as compared to RSAH. The Performance of CSAH is more than 7.17% and 12.41% as compared to RSAH in months of October and December. The finding showed that the CSAH works better than the RSAH in forced convection. In both types of Solar heaters it is found that as enhancement in mass flow rate increase the pressure drop and Nusselt number but the friction factor decreases. Both designs of SAH namely CSAH and RSAH are new in the area of solar air heater and proved to be very effective in transfer the heat and creating the turbulence in the air flow path.

Keywords: Ribs, Cans, Nusselt Number, Peanut.

1. INTRODUCTION

This time world is suffering the large issue of energy utilization due exhaustion of petroleum product resource, and increasing cost of petroleum, diesel fuel and these fuels are additionally establishing the parcel of contamination in climate and is exceptionally hazardous to the human body, ozone layer, and global warming. So, forth a great deal of examination going on the elective energizes in which one of the easily available energies is the sun-based energy since it is normally accessible in the climate and eco-friendly.

So, in this study a can and ribs SAH is design for space heating and crop drying. It totally works on solar energy, so, it cannot be hazardous to human health and environment. Some researchers have worked in this field.[1)] developed a SAH fully furnished with cross over and isolated ribs and calculated friction and heat transfer properties of that SAH.[2)] developed part of the heat loss in flat-board solar absorber happens by means of the upper covering, on the grounds that the base and dividers of the absorber were very much protected.[3)] presented the impact of helical channel on the exhibition of a SAH was researched completely. The development of this investigation was planned a three-sided cross-area channel, in such an approach to set up a helical air flow through the air heater, in which the air flow transfer heat with the base and the top of the absorber plate and calculated the heat flow, friction coefficient and performance of SAH.[4] utilized the of porous medium to expands the surface area to-volume proportion and found that the effectiveness of SAH was increased.[5] provided the angle of ribs on SAH and calculated the influence of angled ribs on HTR and pressure drop.[6] have explored experimentally performance of a sun powered air heater with permeable absorber plate and baffles to develop a helical way.

[7]studied air heaters and analysed, in particular a solitary chamber one and a double chamber one and revealed the effect of collectors on various parameters such as MFR, Moisture and efficiency.[8] developed heat pipe technology for the drying od peanuts with effectivness.[9] carried a study of various V- ribs of roughened plate with Reynolds numbers 2000-20000 and the study revealed that the heat transfer rate enhanced drastically.[10] provided the ribs in circular cross area and revealed the effect on MFR and heat transfer into a channel. Based on circular ribs a relationship was drawn between Nu and pressure drop.[11] at different rib and tendency points, their results uncovered that, at Re of 21000, the ideal estimation of the thermo hydraulic execution was 2.13 relating to ideal roughness parameters at Reynolds number of 21000.[12] reported that a parametric examination on a finned and baffled SAH with conventional SAH and found that the performance of conventional SAH was much lower than the Finned and baffled SAH for many parameters.[13] developed a SAH facilitate with arced artificial roughness in wire form and studied the impact of angle of arc and height of roughness for Re range 2000–17,000 on Nu and friction coefficient.[14] Designed and studied the new absorber for double pass SAH.

The new and novel SAH was developed from conductive aluminum tubes which carry the air stream inside the SAH.

This design of the aluminium can is not very popular in the previous literature. So the testing and analysis of the SAH is very much required for the social benefit since it is very economical and can be made by the simple bear can that has been wasted. The purpose of this study is to compare the TSAH and RSAH performance at varying mass flow rate in winter season in October and December months of the year. The new SAH performance was analyzed at different MFR of air inside the SAH. In addition, TSAH and RSAH were compared with same material and dimensions. Demonstrated that the performance of TSAH found high as compared to FSAH in following parameters such as; lower heat loss, high outer temperature, efficiency net energy addition. TSAH accomplishes extreme air temperature rise in excess of 6 °C compared with FSAH at 0.025 kg/s. TSAH efficiency was found more prominent than FSAH efficiency by about 19.4%, 21%, and 40.3%, flow rate at inlet of 0.075 kg/s, 0.05 kg/s and 0.025 kg/s, respectively.

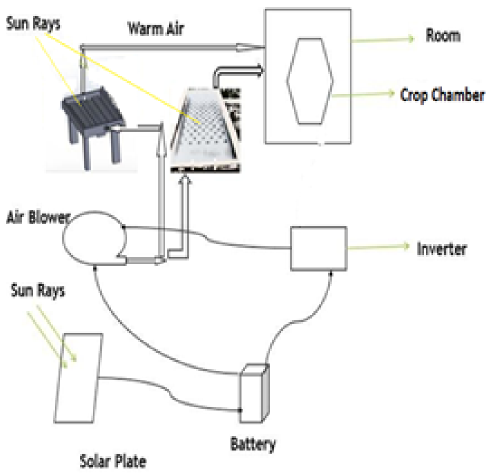
The outlet air temperature and surface energy loss of the TSAH decline with increasing the MFR of air, while its efficiency, pressure drop and output energy increased.[15] developed dimple formed artificial roughness arranged in a angular manner to explore the thermal properties of SAH and found that as the roughness value increased the value of Nusselt number increased.[16] examined proficiency of air heater. As per the consequences of this exploration, greatest proficiency was acquired at a mass flowrate of 0.036 and with a dark black glass.

2. Experimental Set-up

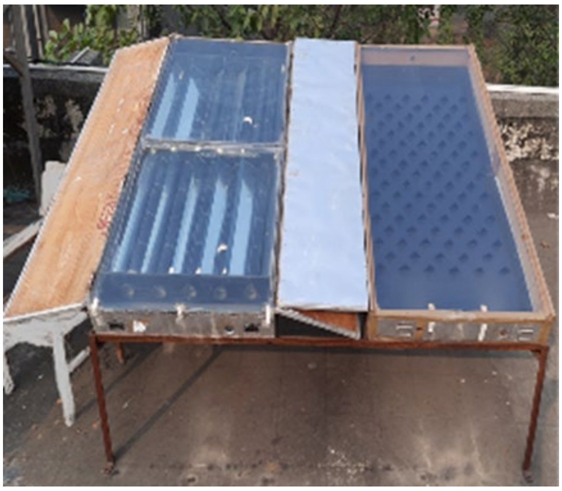
In this study two set are designed and developed, one is prepared with the help of tin cans and other with the help of triangular ribs over the absorber plate. In both the setup black painted absorber plate is used for absorbing the maximum sun energy. The length and width both the setup are 1.8 m and .92 m respectively. In CSAH, black painted tin cans 5 pipes have used over the absorber plate to absorb the maximum solar energy from the sun. In RSAH, black painted triangular ribs are used over the absorber plate to improve the heat transfer surface area. A 5 mm thick transparent mirror is used on top surface of both the setup and in CSAH extra arrangement of reflecting mirror is done around the cans for the enhancement of solar intensity on absorber plate.

A crop drying chamber which is made of wood for drying crops like coconut. The size of the chamber is .76 m*.76m*1.524m. It is divided into three sections with iron mesh and two holes are provided in this chamber for the circulation of hot air flow. Figure 1 (a), (b) & (c) represents experimental setup and crop drying chamber respectively. These setups are used for space heating and crop drying in winter and rainy season respectively. The different types of crops can be dried in crop chamber with the help of heated air comes from CSAH and RSAH.

The main purpose for this research was to made a comparison between the can and ribs solar air heater in month of the winter. A drying chamber has been used for drying the peanut crop. The drying chamber has been provided by the partition of the sieve having the outer frame of the wood. So, when hot air passes through bottom to top of the drying chamber. It will automatically move in upward direction and supplying the energy of the various section of the peanut crop. In this arrangement most of the enrgy of the heat has been absorbed by the peanut and it will loose the moisture content in minimum time.



(a). Schematic Diagram of Experimental Setup


(b). Cans and Ribs SAH


(c). Crop Drying Chamber

Figure 1: Picture of experimental set up

3 Governing Equations

In present work governing equations and empirical relations are used to study the system parameters. The detailed equations and relations are given below.

Kays Equation

$$Nu = 0.0158Re^{0.8} \tag{1}$$

Blasius Equation

$$f = 0.079Re^{-0.25} \tag{2}$$

Pressure Drop

$$\delta P = 2f\rho LV^2/d_e \tag{3}$$

Reynolds Number

$$\mathrm{Re} = \rho V d_e/\mu \tag{4}$$

Heat Transfer

$$Q = mC_p(T_{out} - T_{in}) \tag{5}$$

Thermal Efficiency

$$\eta = Q/qA \tag{6}$$

4 Analysis of Crop Drying

In this analysis peanuts are used as a crop and some data is taken for peanuts from a paper is referred as [12] "Drying peanut seed using air ambient temperature at low relative humidity" as per this paper the 34 kg peanuts take 14 hrs 11 minutes to reduce the moisture contents from 17.4 to 7.3 %.

In our analysis, model equations and experimental results are used to carry out the time analysis for aforesaid data. The equations and are given below:

$$T = \left(m_p(m_2 - m_1)h_{fg} + m_P C(T_{P2} - T_{P1})\right) * \left(m_a(h_2 - h_1)\right)^{-1} \tag{7}$$

The average temperature of CSAH is 65.16 °C at outlet but due to some losses like conduction and radiation the

$$h_1 = 1.005\,T_1 + m_1(1.005\,T_1 + 2500) \tag{8}$$

$$h_2 = 1.005\,T_2 + m_2(1.005\,T_2 + 2500) \tag{9}$$

temperature at the inlet of crop drying chamber is approximately 50°C. In our analysis, time required is 18 hrs. to reduce the moisture contents from 17.4 to 7.3 % but our set up is very simple and economical.

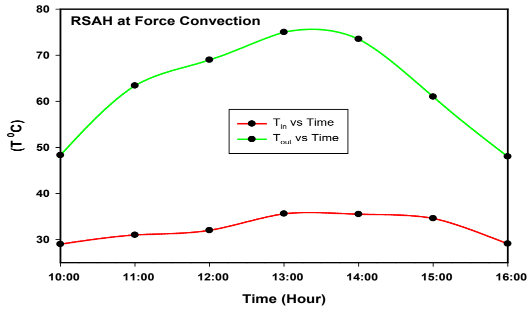
5. Results and Discussion

In the present work experimental investigation is carried out in the month of October 2020 & December 2020 at MJPRU, Bareilly, U.P. India at location 28° N and 73.5° E. The purpose is to design an efficient and economic solar air heater for the space heating and crop drying purposes in winter and rainy season. In this study based on experimental results, the following performance parameters has been determined like HTR, Efficiency, Nusselt Number, Friction Factor and Pressure drop.

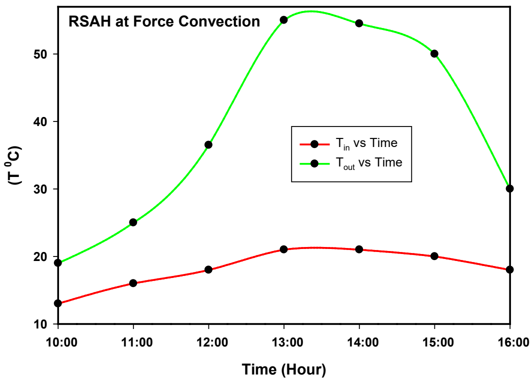
5.1 Inlet and Exit Temperature Variation with time of the day in Months of October and December

5.1.1 Tempertaure variation in RSAH

Figure 2 (a) & (b) shows the variation of exit and inlet temperature of the RSAH w.r.t. time of the day. As, it is seen that exit temperature and the inlet temperature both are increased from morning to noon but start to reduces afternoon since solar flux intensity increased from morning to noon and reduces in evening time. So, the average of temperature difference (Tout -Tin) is 30.18℃ in October and 20.42 ℃ in December respectively[17].



(a) Temperature vs Time (October)

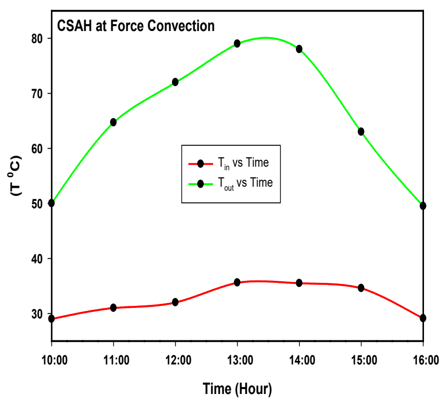


(b) Temperature vs Time (December)

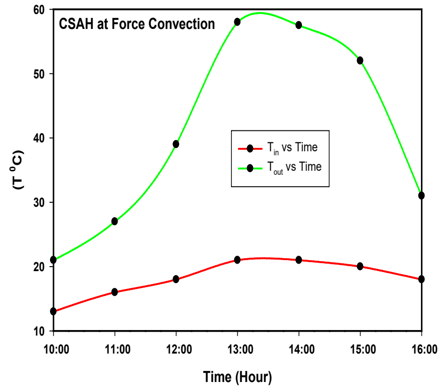
Figure 2: Temperature variation of RSAH with time of the day

5.1.2 Temperature variation in CSAH

Figure 3 (a) & (b) shows the variation of exit and inlet temperature of the CSAH w.r.t. time of the day. As, it is seen that exit temperature is more than the inlet temperature during different time of the day and the reason for this is also similar to the RSAH the only difference is due to increased surface area and the cans are at focus point of the reflecting mirrors due to which heating of the air is increased[18]. So, the average of temperature difference (Tout -Tin) is recorded 32.77 ℃ in October and 22.64 ℃ in December respectively.



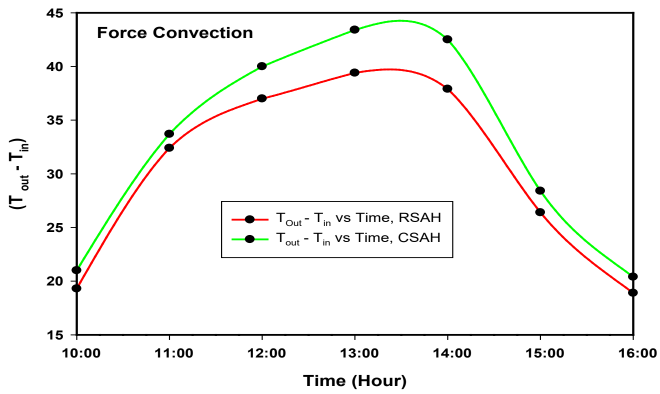
(a) Temperature vs Time (October)



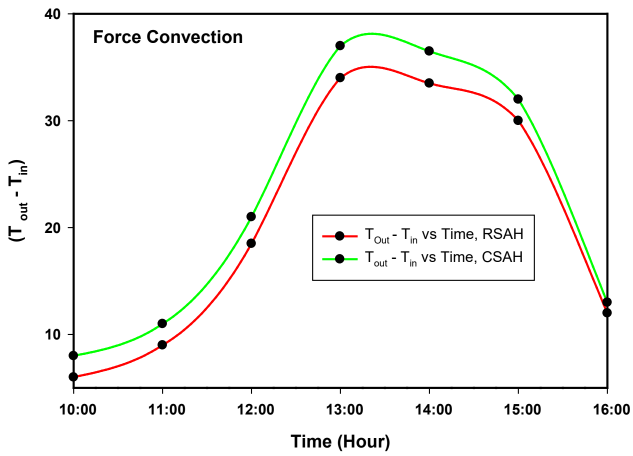
(b) Temperature vs Time (December)

Figure 3: Temerature Variation in CSAH

5.2 Comparison of temperature rise in CSAH and RSAH



(a) (Tout-Tin) vs Time (October)



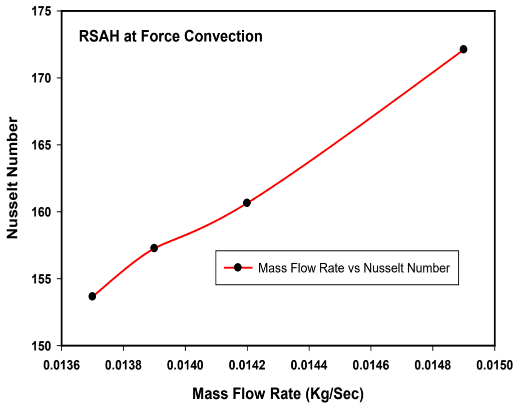
(b) (Tout-Tin) vs Time (December)

Figure 4: Temperature difference between RSAH and CSAH

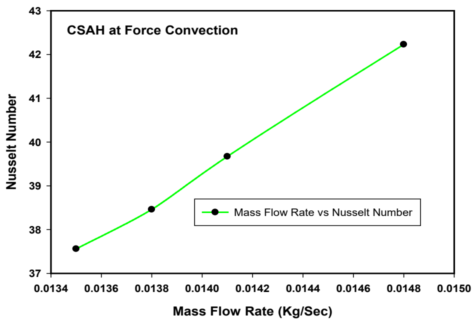
Figure 4(a) & (b) during the same time of the day the higher exit temperature is deliver by CSAH as compared to RSAH because in CSAH the heating of the air is done by three ways (i) solar flux is absorbed by the absorber plate at the base. (ii) heat is also absorbed by the tin cans tube arrangement and (iii) the tin cans tubes are also situated at the focal point of the reflecting mirrors attached at both side of the tubes. In case of CSAH the exit temperature is higher by 8.58% as compared to RSAH in October and 10.87% in December respectively.

5.3 Nusselt Number comparison in both RSAH and CSAH

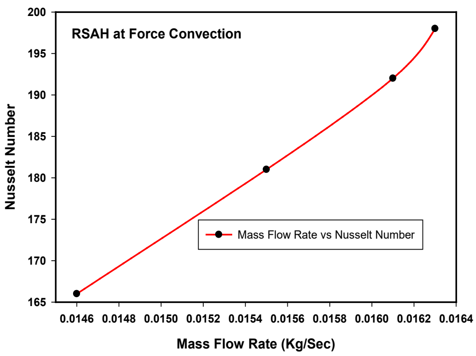
Figure 5 (a), (b), (c) & (d) represents the variation of Nusselt number with MFR. The trend of the plot represent in aforesaid cases Nusselt number is increasing with MFR since increase in mass flow rate increase the Reynolds Number so as per equation (1), the enhancement in mass flow rate enhance the Nusselt Number but the value of Nusselt number in RSAH case is high as compare to CSAH. This is due to the fact in RSAH the value of turbulence is high which will further increase the heat transfer rate. The variation of Nusselt number in RSAH is 153-172 in October and 166-198 in December respectively and in CSAH is 37-42 in October and 41-48 in December respectively[19]. The Nusselt Number helps to determine the heat transfer coefficient and heat transfer.



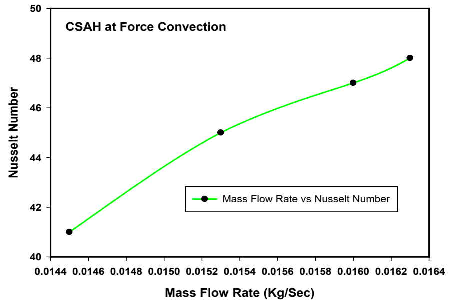
(a) Nusselt Number variation in RSAH (October)



(b) Nusselt Number Variation in CSAH (October)



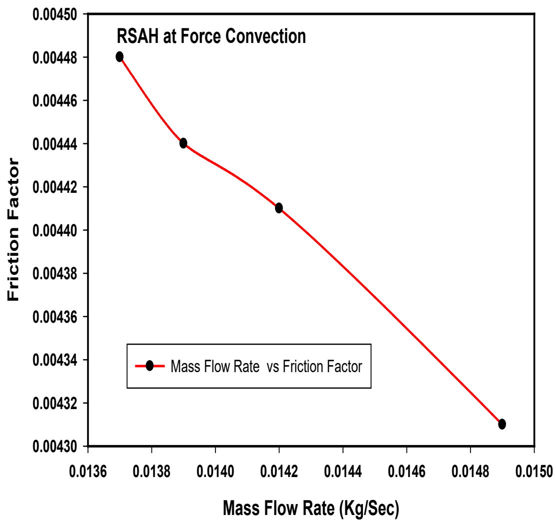
(c) Nusselt Number variation in RSAH (December)



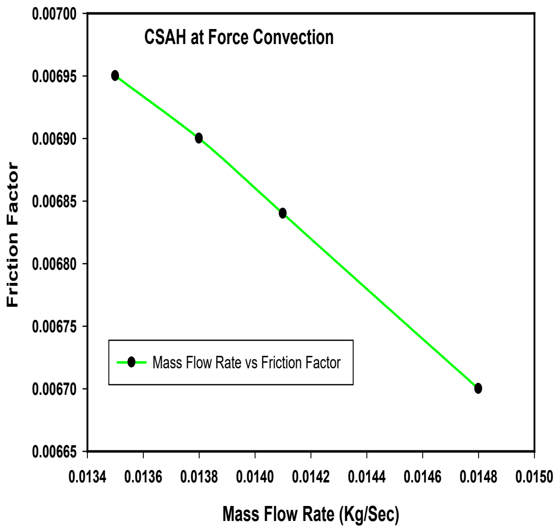
(d) Nusselt Number Variation in CSAH (December)

Figure 5: Nusselt Number variation in October and December Months

5.4 Friction Factor variation in CSAH and RSAH

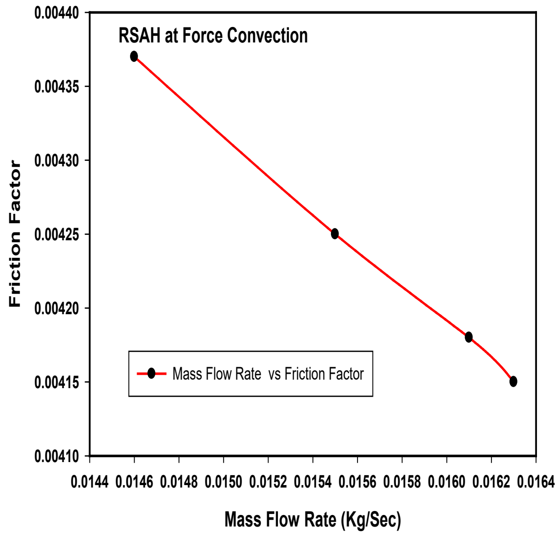


(a) Friction Factor variation in RSAH (October)

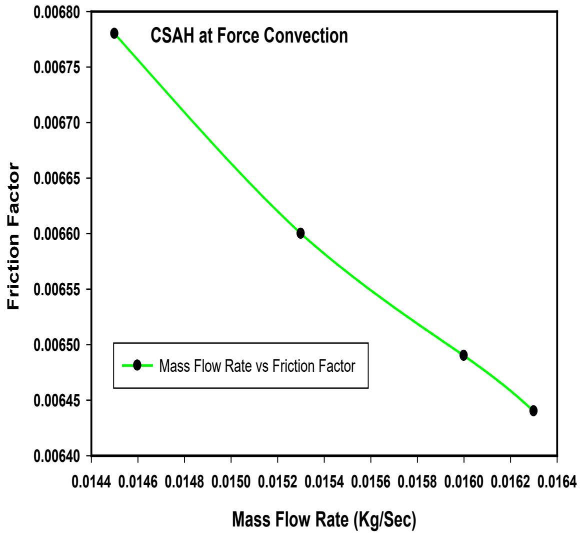


(b) Friction Factor Variation in CSAH (October)

Figure 6 (a), (b), (c) & (b) represents the variation of friction factor with MFR. The trend of the plot represent in the aforesaid cases friction factor is decreasing with mass flow rate because friction factor is inversely proportional to the Re and Re is increasing with mass flow rate. In CSAH the value of friction factor is high as compare to RSAH. The average friction factor in RSAH is .00440 in October and .00426 in December respectively and in CSAH is 0.00683 in October and 0.00661 in December respectively.



(a) Friction Factor variation in RSAH (December)

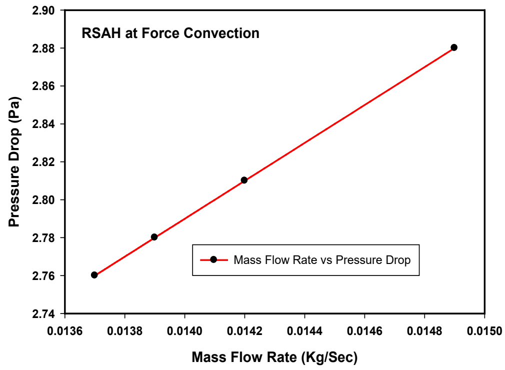


(b) Friction Factor Variation in CSAH (December)

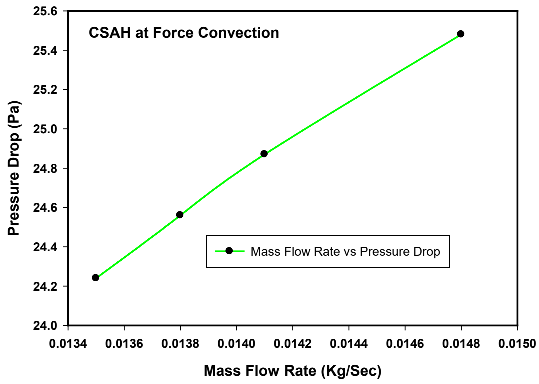
Figure 6: Friction Factor variation with mass flow rate

The friction factor calculation helps to determine the pressure drop in the solar air heater duct. The increase in pressure drop further increase the blower and reduces the net thermal efficiency of solar air heater. So, thermal hydraulic performance analysis of solar air heater has been done by knowing the value of the pressure drop. Some time enhancement of the Nusselt Number on roughned surface not justified due to increase of pressure drop.

5.7 Pressure Drop with mass flow rate



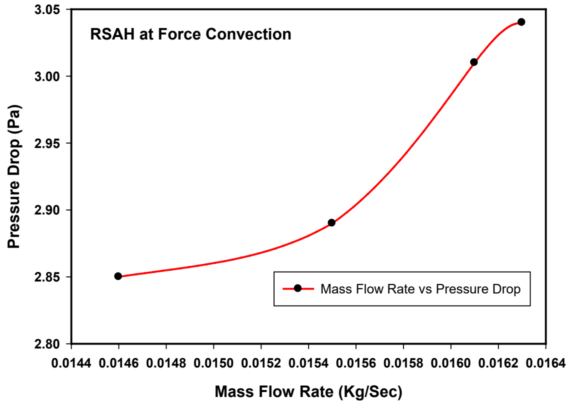
(a) Pressure Drop in RSAH (October)



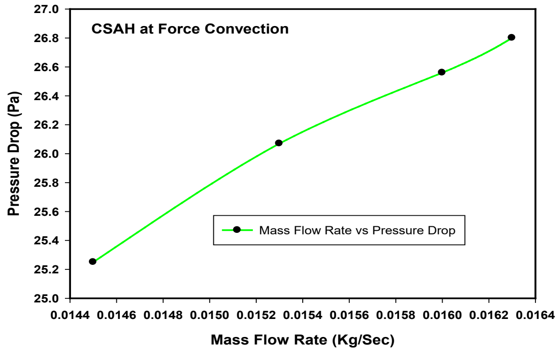
(b) Pressure Drop in CSAH (October)

Figure 7 (a), (b), (c) & (d) represents the variation of Pressure drop with MFR. The trend of the plot represent in both the cases pressure drop is increasing with mass flow rate because friction factor is inversely proportional to the Reynolds number[20]. In CSAH the value of pressure drop is high as compare to RSAH because equivalent diameter for CSAH (de = 0.05 m) is quite low as compare to RSAH (de= 0.286 m). The average pressure drop in RSAH is 2.67 Pa in October and 2.92 Pa in December respectively and in CSAH Pa is 24.86 Pa in October and 25.96 Pa in December respectively.

The experimental measurement of the pressure drop in the solar air heater has been done by the micromanometer. It helps to determine the friction factor on the both solar air heater since it is quite tough to develop a emerical relation saperately for the both geometries CSAH and RSAH.



(c) Pressure Drop in RSAH (December)



(d) Pressure Drop in CSAH (December)

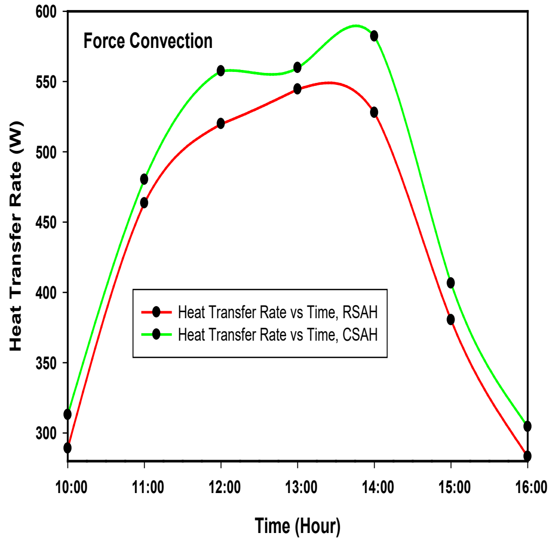
Figure 7: Presure variation with mass flow rate in CSAH and RSAH

5.8 Heat transfer rate in CSAH and RSAH

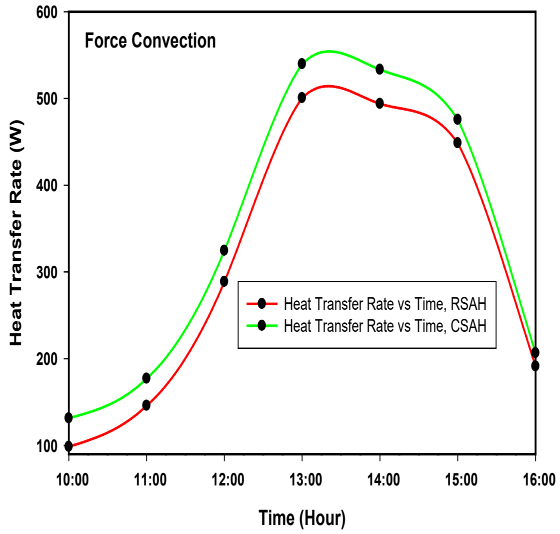
Figure 8 (a) & (b) represents the variation of HTR with Time. The value of heat transfer rate for CSAH is high as compare to RSAH because the difference between exit and inlet temperature is more as shown in figure 4(a) & (b) to RSAH and the effect of change in density is negligible as compared to temperature change[21),22),23)]. The value of heat transfer rate in CSAH is 7.59 % more than the RSAH in October and 10.17% in December respectively.

The heat transfer rate calculation in the solar air heater is futher used for calculation of the thermal efficiency of the solar air heater. The higher heat transfer rate represents the higher thermal efficiency and effectiveness of the Solar Air heater.

The turbulence in the air flow enhance the heat transfer rate but increased roughness also increase the blower power.



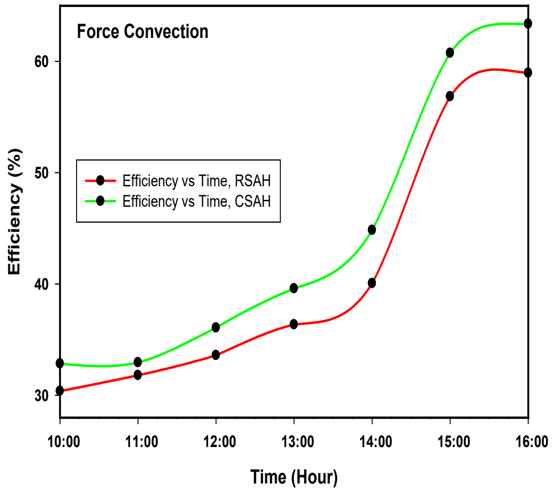
(a) HTR vs Time (October)



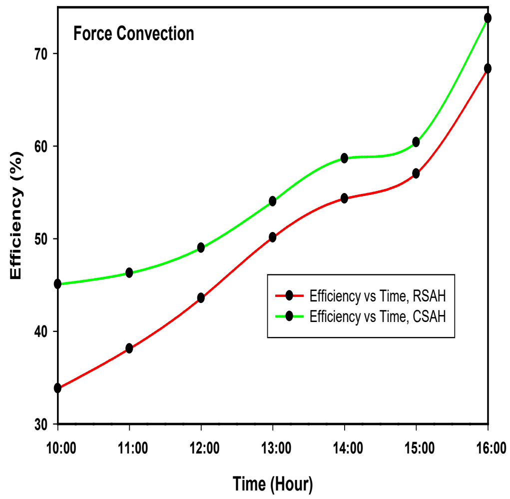
(b) HTR vs Time (December)

Figure 8: Heat transfer rate variation in CSAH and RSAH

Figure 9 (a) & (b) shows the variation of efficiency with Time. In both the cases efficiency is increasing with solar flux up to 1:00 PM. After 1:00 PM solar flux is decreasing[24),25),26)] but still the efficiency of the both SAH is increasing the reason for this both the SAH store heat in the form of internal energy. The efficiency of CSAH is 7.77% more than the RSAH in October and 12.41% in December respectively.



(a) Efficiency vs Time (October)



(b) Efficiency vs Time (December)

Figure 9: Efficeincy variation with CSAH and RSAH

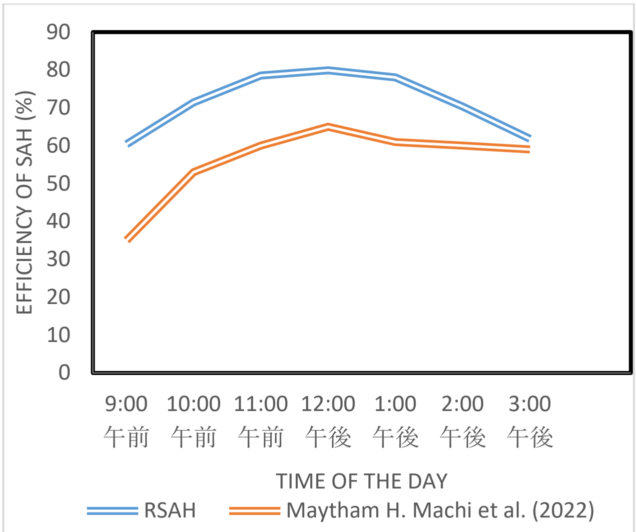
6. Validation of Results of RSAH with the Maytham H. Machi et al. (2022)

The RSAH validated with the triangular fins solar air heater work published by the Maytham H. Machi et al. (2022). Table 1 represents the difference in the geometry of the both type of the solar air heater. It can be clearly seen from Table 3, the dimensions of the box of the RSAH and number of fins are quite larger than the [27] due to that the heat absorbed by the RSAH and the heat transfer by the fins are larger than the [27].

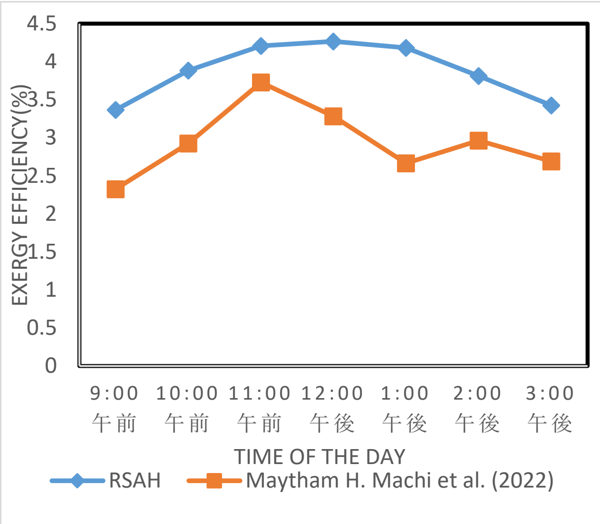
Table 1: Design of RSAH and the [27]

RSAH					
Box Size			**Fin Dimensions**		
Length	**Width**	**Height**	**Base**	**height**	**number of Fins**
1800 mm	920 mm	140 mm	25.4 mm	50 mm	94
Maytham H. Machi et al. (2022)					
Box Size			**Fin Dimensions**		
Length	**Width**	**Height**	**Base**	**height**	**number of Fins**
1200 mm	500 mm	150 mm	100 mm	40 mm	18

Figure 10 (a) and Figure 10 (b) show that the thermal efficiency and exergy efficiency of RSAH is higher than the [27] since the number of fins in RSAH is higher than the [27] as presented in Table 1.



(a). Validation of efficiency of RSAH



(b). Validation of exergy efficiency of RSAH

Figure 10: Validation of RSAH results with [27]

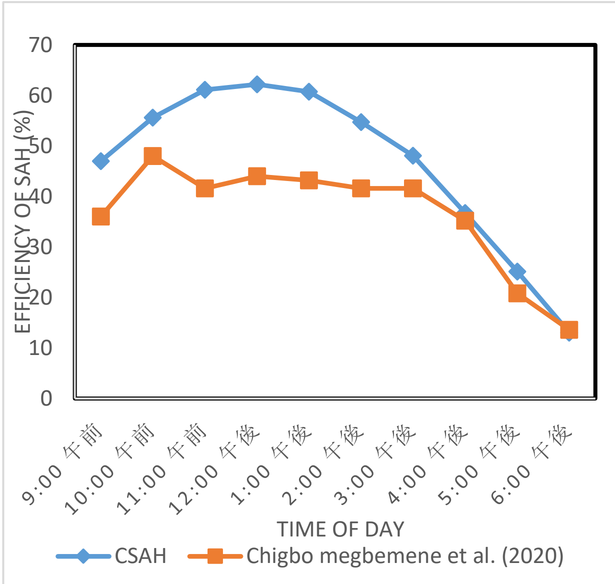
7. Validation of Results of CSAH with the Chigbo megbemene et al. (2022)

The details of the CSAH and the Chigbo megbemene et al. (2022) is given in Table 2.

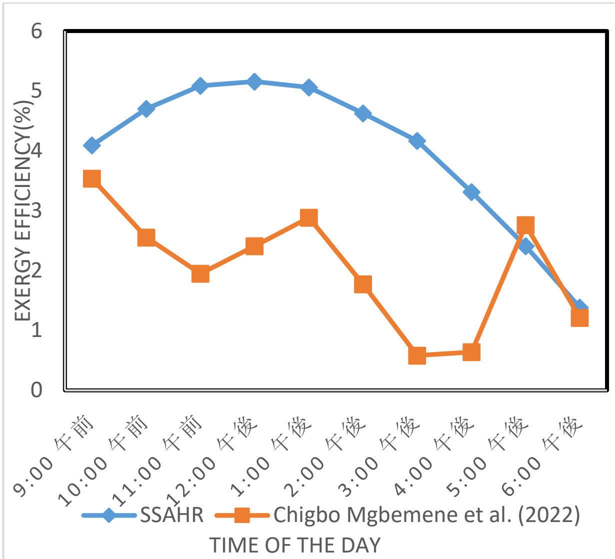
Table 2: Design parameters of SSAHR and [28]

CSAH					
			Tin can Dimensions		
Length	**Width**	**Height**	**Diameter**	**height**	**Number of Tin cans**
1800 mm	920 mm	140 mm	60 mm	166 mm	132
Chigbo megbemene et al. (2022)					
			Soda cans Dimensions		
Length	**Width**	**Height**	**Diameter**	**height**	**Number of soada cans**
2134 mm	1067 mm	150 mm	65 mm	110 mm	240

Figure 11 (a) and Figure 11 (b) shows that thermal efficiency and exergy of CSAH is higher than the [28] since the length of solar air heater in [28] is higher than CSAH which increase the energy loss of the air.



(a). Validation of thermal efficiency



(b). Validation of Exergy

Figure 11: Validation of CSAH results with [28]

8. Conclusion

In the present work the experimental analysis of solar air heater with two different geometries configurations are tested for the weather condition of Bareilly city UP, INDIA in the winter season and the following conclusions are made from the experimental findings:

1- In RSAH at force convection the enhancement in average temperature difference (Tout -Tin) is found 30.18 ℃ in October and 20.42 ℃ in December respectively.

2- In CSAH at force convection the enhancement in average temperature difference (Tout -Tin) is found 32.77 ℃ in October and 22.64 ℃ in December respectively.

3- The average exit temperature in CSAH compare to RSAH is increased by 8.58 % and 10.87 % in the month of October and December respectively.
4- The average value of HTR in CSAH compare to RSAH is 7.59% and 10.17 % more in the month of October and December respectively.
5- The average efficiency in CSAH compare to RSAH is 7.77% and 12.41 % more in the month of October and December respectively.

Hence, it may be concluded that CSAH may be better alternate compare to RSAH in the case of force convection. In this study 34 kg of peanuts are dried in 18 hrs.

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Nomenclature

RSAH	Ribs Solar Air Heater
CSAH	Cans Solar Air Heater
TSAH	Tubular Solar Air Heater
FSAH	Flat Plate Solar Air Heater
MFR	Mass Flow rate
HTR	Heat Trasfer Rate
η	Efficeincy (%)
v	Kinematic Viscosity (m^2/s)
f	Friction Coefficient
δP	Pressure Drop
ρ	Density (Kg/m^3)
μ	Dynamic Viscosity (Kg/m.sec)
Re	Reynolds Number
T	Time in (hrs)
mp	mass of Peanuts
ma	mass flow rate (Kg/sec)

References

1) Aharwal, K.R., Bhupendra, K.&Saini, G.J. (2009). Heat transfer and friction characteristics of solar air heater ducts having integral inclined discrete ribs on absorber plate. Int. J. Heat Mass Transf., 52, 5970–5977.
2) Alam, T., Saini, R.P.&Saini, J.S. (2014).Use of turbulators for heat transfer augmentation in an air duct – a review. Renew. Energy, 62, 689–715.
3) Ali Hayderi&Mehrdad Mesgarpour (2018). Experimental analysis and numerical modeling of solar air heater with helical flow path. Solar Energy,162, 278–288.
4) Bayrak, F., Oztop, H.F. &Hepbasli, A. (2013). Energy and exergy analyses of porous baffles inserted solar air heaters for building applications. Energy Build, 57,338–345.
5) Choi, E.Y., Choi, Y.D., Lee, W.S., Chung, J.T. & Kwak, J.S. (2013). Heat transfer augmentation using a rib–dimple compound cooling technique. Applied Thermal Engineering, 51, 435–441.
6) Devecioglu, A.G. &Oruc, V. (2017). Experimental investigation of thermal performance of a new solar collector with porous surface. Energy Procedia,13, 251–258.
7) Forson, F.K., Nazha, M.A. & Rajakaruna, H. (2003). Experimental and simulation studies on a single pass, double duct solar air heater. Energy Convers. Manage., 44 (8), 1209–1227.
8) Francisco Carlos Krzyzanowski, Sherlie Hill West&José de Barros França Neto (2006). Drying peanut seed using air ambient temperature at low relative humidity. Rev. bras. Sementes, 28 (3), 2006, Pelotas, http://dx.doi.org/10.1590/S0101-31222006000300001.
9) Hans, V.S., Saini, R.P. &Saini, J.S. (2010). Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with multiple v-ribs. Solar Energy,84, 898–911.
10) Karmare, S.V. &A. N. Tikekar, A.N. (2007). Heat transfer and friction factor correlation for artificially roughened duct with metal grit ribs. International Journal of Heat and Mass Transfer,50, 4342-4351.
11) Kumar, A. & Layek, A. (2018).Thermo-hydraulic performance of solar air heater having twisted rib over the absorber plate. Int. J. Therm. Sci.,133, 181–195.
12) Mohammadi, K. & Sabzpooshani, M. (2013). Comprehensive performance evaluation and parametric studies of single pass solar air heater with fins and baffles attached over the 25-absorber plate. Energy,57, 741–750.
13) Saleh Abo-Elfadla, Hamdy Hassana&M.F. El-Dosokya,c. a. (2020).Study of the performance of double pass solar air heater of a new designed absorber: An experimental work. Solar Energy, 198, 479–489.
14) Saini, R.P. & Verma, J. (2008). Heat transfer and friction factor correlations for a duct having dimple-shape artificial roughness for solar air heaters. Energy,33, 1277–1287.
15) Sethi, M., Varun, Thakur, N.S. (2012). Correlations for solar air heater duct with dimpled shape roughness elements on absorber plate. Solar Energy, 86, 2852–61.
16) Vaziri, R., İlkan, M. & Egelioglu, F. (2015). Experimental performance of perforated glazed solar air heaters and unglazed transpired solar air heater. Solar Energy, 119, 251–260.
17) Louay A. Rasheed, Jamal A. K. Mohammad, Raed A. Jessam (2023) "Performance enhancement of single pass solar air heater by adopting wire mesh absorber

layer," Evergreen., vol. 10(2) pp.880–887 (2023). https://doi.org/10.5109/6792883

18) Saifullah Zaffar, Chandrashekhara M, Gaurav Verma "Thermal Analysis of an Evacuated Tube Solar Collector using a One-end Stainless Steel Manifold for Air Heating Applications under Diverse Operational Conditions," Evergreen, vol. 10(2) pp.897-911 (2023). https://doi.org/10.5109/6792885
19) Vineet Singh, Vinod Singh Yadav, Abdulwasa Bakr Barnawi, Javed Khan Bhutto, Rajesh Verma, Pushkar Singh and Niraj Kumar "Comparison of different designs of solar air heater with the simple solar heater of having reflecting mirrors," Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, doi: 10.1177/09544062231158530.
20) Niraj Kumar, Manoj Kumar Singh, Vinod Singh Yadav, Vineet Singh, Anurag Maheswari "An Experimental Investigation of Ribbed Solar Air Heater—Free Convection," Recent Advances in Industrial Production: Select Proceedings of ICEM 2020, pp. 373–381, 2022, doi: 10.1007/978-981-16-5281-3_35.
21) Kim, Young Deuk, Kyaw Thu, and Kim Choon Ng. "Evaluation and parametric optimization of the thermal performance and cost effectiveness of activeindirect solar hot water plants." Evergreen 2(2) pp.50-60 (2015). https://doi.org/10.5109/1544080
22) Tewari, Kirti, and Rahul Dev. "Analysis of modified solar water heating system made of transparent tubes & insulated metal absorber." Evergreen Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy 5(1) pp.62-72 (2018). https://doi.org/10.5109/1929731
23) N. Kumari, S. Kumar Singh, S. Kumar, "Matlabbased simulation analysis of the partial shading at different locations on series-parallel PV array configuration", Evergreen. Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 9(4), pp.1126-1139 (2022). https://doi.org/10.5109/6625724
24) Y.D.Kim, K.Thu, K.Choon Ng, "Evaluation of parametric optimization of the thermal performance and cost-effectiveness of active-indirect solar hot water plants", Evergreen. Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 2(2), 50-60, (2015). https://doi.org/10.5109/1544080.
25) K. Tewari, and R. Dev, "Analysis of modified solar water heating system made of transparent tubes & insulated metal absorber", Evergreen Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 5(1), 62–72, (2018). https://doi.org/10.5109/1929731.
26) Kumar Amit, and Layek Apurba, " Effect of Heat transfer and Pressure Drop characteristicson the performance analysis of an artificial rouughned solar air heater. Heat and Mass Trasfer, 59, 891-907, (2023).
27) M. H. Machi, M. A. Al-Neama, J. Buzás, and I. Farkas, "Energy-based performance analysis of a double pass solar air collector integrated to triangular shaped fins," *Int. J. Energy Environ. Eng.*, vol. 13, no. 1, pp. 219–229, Mar. 2022, doi: 10.1007/S40095-021-00422-Z/TABLES/1.
28) C. Mgbemene, I. Jacobs, A. Okoani, and N. Ononiwu, "Experimental investigation on the performance of aluminium soda can solar air heater," Renew. Energy, vol. 195, pp. 182–193, Aug. 2022, doi: 10.1016/J.RENENE.2022.06.011.