SEMARAK ILMU PUBLISHING

Semarak Engineering Journal

Journal homepage:
https://semarakilmu.com
ISSN: 3036-0145



Investigation of a Solar Air Heater with Transversely Curved Fins Theoretically

Mazin Y. Abdul-Kareem[1,*], Ahmed F. Khudheyer[1]

[1] Al-Nahrain University, Engineering College, Baghdad, Iraq

ARTICLE INFO

Article history:
Received 20 July 2025
Received in revised form 29 November 2025
Accepted 10 December 2025
Available online 15 January 2026

Keywords:

Curvy fin; thermal performance; collector dimension; SAH

ABSTRACT

A theoretical investigation has been conducted into the effects of dimension for collector on the rate of heat transmission and pressure decrease (ΔP) parameters of a ΔP through solar air heaters (SAH) with curved fins. The flow channel was formed by two crosswise positioned, curvy fins placed beneath the plate used for absorption, and a uniform heat flux was given to the top surface. The effects of collector length and mass flow rate on a SAH with curvy fins were studied. Through research, it has been determined that as collector length rises, Likewise, complete loss, pressure decreases, and useful energy gain do. Nevertheless, the thermal efficiency of solar air heaters declines. Furthermore, the exit air temperature decreases the SAH due to a decreased mass flow rate. Lower mass flow rates also result in an increase in the temperature of the exit air and a decrease in the pressure drop. The curved fin solar air heater's pressure drop rises from 5.12% to 19.2% at a mass flow rate of 0.0114 kg/s. Concurrently, the curvy fin's increased output air temperature results in a decrease in pressure and an increase in overall efficiency. Additionally, it has been demonstrated that the air outlet temperature rises with collector length; however, for the curved air heater, this effect disappears at velocities higher than 0.045 kg/s.

1. Introduction

Due to their relatively low cost, solar air heaters (SAHs) are extensively employed in electrical and mechanical engineering applications. Flat-plate collectors are capable of harnessing both diffuse and direct solar radiation and operate based on a simple working principle, resulting in low construction costs and ease of implementation [1]. Solar energy is used in flat-plate collectors to heat the air. Solar heaters have a low thermal efficiency due to the little heat transmission between the surface of the absorber and the environment [2]. Given the usage of thermally insulated sides and a bottom wall, heat lack via the upper glass panel must be another factor. Numerous experimental studies [3–11] have been conducted to increase thermal efficiency in thermal systems that employ air as a heat-transfer fluid. Biondi *et al*., [3] investigated the thermodynamic characteristics of SAH with standard designs—one or two passes and one or double cover glasses. Two factors were used to generalize

* *Corresponding author.*
E-mail address: mazin.y.abdulkareem@nahrainuniv.edu.iq

their research: the collector geometric coefficient (K) and the air mass flow rate per unit collection area (G), which, given the same design, material, and ambient value conditions, made collector characteristics constant. Use the same design parameters, material choices, and environmental values in a model with zero- capacitance.

The air heater performances were examined using a zero-capacitance model, and the graphs that are shown can be used to address air collector planning issues. Furthermore, Choudhury and Garg [4] conducted thermal research on one-pass corrugated and surface plate SAH in five distinct designs with varying air duct lengths and air mass flow rates($\dot{m}$). Using their styling study and turns, a designer may create affordable SAH with technically sound air passage proportions. Choudhury *et al*., [5] carried out an additional study to examine the effectiveness of corrugated one-pass air heaters with different air duct widths and ($\dot{m}$). Furthermore, the optimization's sensitivity to alteration in SAH parameters and working situations is evaluated. An evaluation of the effectiveness of a "V" corrugated-plate SAH on clear winter and summer days was carried out by Joudi and Mohammad [6]. With a mean collector competence of 42%, a summer midday air exit temperature of 70°C was achieved. Study on the solar flat collector using air as the fluid was conducted by Ghodbane *et al*., [7]. The sun radiation and the effects of different parameters were calculated at several Algerian locations. These air warmers are beneficial for drying purposes as well as for winter use, according to their findings. It is generally accepted that introducing fins to the flow path is a good method to increase heating efficiency, and numerous comparisons with various fin designs have been carried out under different conditions of operation.

For instance, Tanda [8] examined the heat transfer and friction coefficients of the heating systems to experimentally evaluate the comparative advantages of various rib layouts under various Reynolds numbers. Based on their findings, Karim and Hawlader [9] suggested a particular airflow rate for drying, taking into account the exit air temperature and efficiency of the v-design heater, which operates at greater efficiency than the traditional planar collector. Y.C. et al. [10] proposed a solar air heater (SAH) design in which aluminum wool was integrated into a perforated plate located within the airflow duct. They then compared the solar air heater's thermal performance to that of the conventional heater with regard to the rise in output air temperature under the identical operating conditions. Research has shown that the absorber plate's tiny fins can increase convective heat transmission in the airflow duct without significantly lowering pressure. According to Youcef-Ali [11,12], the offset strip fin might ensure low pressure losses in the heater and increase the convective heat transmission area per unit volume. Next, in order to build heaters, they created a heat transmission model [13]. In order to investigate the limitations of the technology and maximize the overall amount of energy harvested by the system, first law and second law analyses of a water-cooled PV/T module have been addressed [14]. To determine the output air temperature, collector efficiency, and heat transfer, Vinod and Shailendra [15] conducted an experimental analysis and performance comparison of a cross flow SAH with an line puncture jet plate and a staggered puncture jet plate. When compared to staggered hole plate solar air heaters, they discovered that inline hole jet plates performed better. It is clear from the previously mentioned literature review how the curvy fins must be utilized for thermodynamic evaluations of solar air heaters. The aforementioned item served as inspiration for a completely developed turbulent flow air heater with a curvy fin's mathematical modeling.

2. Methodology

According to assumptions that can be considered as steady state, no slip boundary condition, laminar flow, constant thermal physical properties and two-dimensional flow, insulated the vertical

walls. As depicted in Figure 1, examine an air heater solar with an absorber surface with length (L) and width (W). It has (n) number of fins with uniform thickness (δ_f) and height (h_f) positioned at a typical distance of (w). Figure 2 displays the graphical characteristics of a fin. There is a (H)-shaped space between the absorber plate and the bottom plate. The absorber plate and bottom plate are heated by a single pass of the solar air heater. The following calculations, also referred to as the Hottel-Whiller-Bliss equation [1], provide the solar air heater's steady state efficiency.

$$\eta_{\square} = \frac{Q_u}{A_c \times I} \quad (1)$$

The term used to describe beneficial energy is:

$$Q_u = F_R A_c \,(S - U_L 0 T_{fi} - T_a 23 \quad (2)$$

Using the previously indicated empirical connection, the maximum loss factor (U_t), supplied by Klein, the side loss coefficient (Us), the bottom losing coefficient (U_b), and the total loss coefficient (U_L), denoted as [2], are all assessed.

$$\mathrm{U_L} = \mathrm{U_t} + \mathrm{U_b} + \mathrm{U_s} \quad (3)$$

Where

$$\mathrm{Us} = (\mathrm{L} + \mathrm{W})\mathrm{HK_i}/\mathrm{LW}\delta_\mathrm{s}$$

$$\mathrm{U_b} = \frac{k_i}{\delta_b}$$

$$\mathrm{U_t} = \frac{1}{\left[\frac{N_{gc}}{\frac{\mathrm{C}}{T_{pm}(N_{ge}+f')\ 0.33}\left(\frac{T_{pm}-T_a}{\ }\right)^{\wedge}} + \frac{1}{h_\mathrm{w}}\right]} + \left[\frac{\sigma(T_{pm}^2 + T_a^2)(T_{pm} + T_a)}{\frac{1}{\mathrm{s}_{p+.05N_{gc}(1-\mathrm{s}p)} + \frac{2N_{gc}+f'+1}{\mathrm{s}_c} - N_{gc}}}\right] \quad (4)$$

In this case, the efficiency factor is represented by

$$\mathrm{f}' = (1 + 0.04h_\mathrm{w} + 0.0005h_\mathrm{w}^2)01 + 0.091N_{\mathrm{g}\square}2 \quad (5)$$

$$\mathrm{C} = 365.9(1 - 00883\theta + 0.0001298\theta^2) \quad (6)$$

$$h_\mathrm{w} = 5.7 + 3.8V_\mathrm{w} \quad (7)$$

h_w is coefficient of heat transfer.

The ratio of a plane (flat) rectangular fin set with the same height and length to the surface area used for heat transfer of the curved fins is known as the area improvement factor, or β [2].

For absorber plate;

$$S\& = U_t 0 T_{pm} - T_a 2 + h_{fp} 0 T_{pm} - T_f 2 + h_{ff} \cdot (\frac{2}{\mathrm{w}}3 \cdot h_f \beta \cdot \Phi_f 0 T_{pm} - T_f 2 + h_r 0 T_{pm} - T_{bm} 2 \quad (8)$$

Where Φ_f is the efficiency of fin,
For bottom plate;

$$h_r 0T_{pm} - T_{bm} 2 = h_{fb} 0T_{bm} - T_f 2 + U_b(T_{bm} - T_a) \quad (9)$$

For air stream

$$Q_u = h_{fb} 0T_{bm} - T_f 2 + h_{fp} 0T_{pm} - T_f 2 + (\frac{2}{\mathrm{w}} 3\, h_f \cdot \Phi_f \cdot \beta \cdot h_{ff} 0T_{pm} - T_f 2 \quad (10)$$

$$\Phi_f = \frac{\tanh\, mh_f}{mh_f} \quad (11)$$

$$m = \mathrm{U}\frac{2h_{ff}}{k_a \delta_f}\mathrm{V}^{\frac{1}{2}} \quad (12)$$

$$h_e = h_{fb} + \frac{2h_{fb}h_{ff}}{\mathrm{w}} + \frac{h_r \cdot h_{fb}}{h_r + h_{fb}} \quad (13)$$

One may suppose that the heat transmission coefficients on the three sides of the pass walls and the air are equal, i.e.

$$h_{ff} = h_{fp} = h_{fb} = \frac{Nu \cdot k_a}{D_h} \quad (14)$$

The following correlation for laminar flow in a rectangular duct for air can be applied [1],

$$Nu = 4.4 + \frac{0.00398(0.7\mathrm{Re}\ D_h/L)^{1.66}}{1+0.00114(0.7\mathrm{Re}\ D_h/L)^{1.12}} \quad (15)$$

Using Kay's data and McAdams' adaption for a rectangular channel, the connection for turbulence is found [1].

$$Nu = 0.0158\,\mathrm{Re}^{0.8}\,\mathrm{U}1 + (\frac{Dh}{L}3^{0.7}\mathrm{V} \quad (16)$$

The average plate temperature can be calculated using a Gauss-Siedel method of iteration [2].

$$T_{pcal} = T_a + \frac{Q_u(1-F_R)}{A_p U_L F_R} \quad (17)$$

The SAH outlet temperature can be found by doing the following:

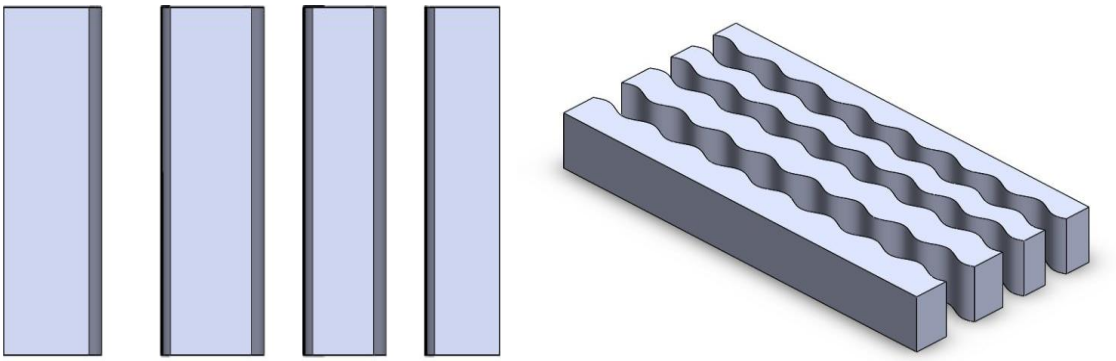
$$\frac{T_{fo}-T_a-S/U_L}{T_{fi}-T_a-S/U_L} = exp\ \mathrm{U}\frac{-A_c U_L F'}{m^o C_p}\mathrm{V} \quad (18)$$

$$f = 0.079Re^{-0.25} \quad (19)$$

$$\Delta P = \frac{4fL\rho v^2}{2D_h} \quad (20)$$



Fig. 1. Flat solar collector



(a) **(b)**

Fig. 2. Curved solar collector

The present case had been simulated by using ANSYS FLUENT R2024, by using a finite volume method. the mesh was generated and considered as hexahedral with best number of 2452214 which dependent and that will not affect on the results as a mesh independence. An uniform mass flow rate at the inlet and zero pressure on the outlet section. The bottom plate considered as insulated as for the vertical sides while the upper plate was an absorber plate, these items are the boundary conditions.

3. Results

The following curves representing the transmission of heat and pressure reduction parameters of the curvy fins air heating system have been plotted based on the theoretical study. The different input parameters that were used in the analysis are listed. The overall loss coefficient as a function of the flow rate of mass and the collector distance is displayed in the table below. It demonstrates that the overall loss coefficient rises with collector length over the whole flow rate of mass range. Up to 1.15 meters of collector length, the curvy fin showed a lower loss factor than a plane at an equal flow rate of mass 0.0114 kg/s; after this length, the curvy fin SAH displayed the greatest entire loss factor. This could be the result of the mean plate temperature rising with increasing collector length, whereas the total loss coefficient falls with increasing mass flow rate for a fixed SAH length. The practical energy represented as a useful energy factor shown that the increase plotted against SAH length and ($\dot{m}$) is displayed in Fig. 3. Gain in usable energy increases with increasing mass flow rate. More usable energy gain is shown by the curvy fin at constant mass flow rates. Gaining more useable

energy corresponds with an increase in SAH length. This occurs as a result of the effective heat transmission area increasing with SAH length. The thermal efficiency as a function of $(\dot{m}_{?})$ and SAH length is displayed in Fig. 4. As SAH length grows, thermal efficiency rises as well. When the SAH length of the curvy fin SAH is increased from 0.2 m to 4 m, the thermal efficiency drops by up to 43% at a constant $(\dot{m}_{?})$ of 0.0138 kg/s. In contrast, a plane's SAH might lose up to 29% of its power. The increased losses that come with longer SAH are the cause of the efficiency decrease. Fig. 5. shows the temperature of the outlet as a function of $(\dot{m}_{?})$ and SAH length. The results indicate that when the SAH length is expanded from 0.2 m to 4 m, the temperature of the outlet rises from 315 K to 383.5 K at lower $(\dot{m}_{a})$. However, when the collector length is increased to 2.4 m and the $(\dot{m}_{a})$ exceeds 0.045 kg/s, the air temperature falls. This could be the result of increased heat losses due to lower absorber plate temperature at higher $(\dot{m}_{?})$ caused by longer SAH. Fig. 6 illustrates how, as SAH length rises, so does the ΔP along the SAH. Less ΔP results from shorter SAH lengths at lower $(\dot{m}_{?})$, yet as SAH long grows, greater amounts of heat is lost to the environment, which raises pressure drop.

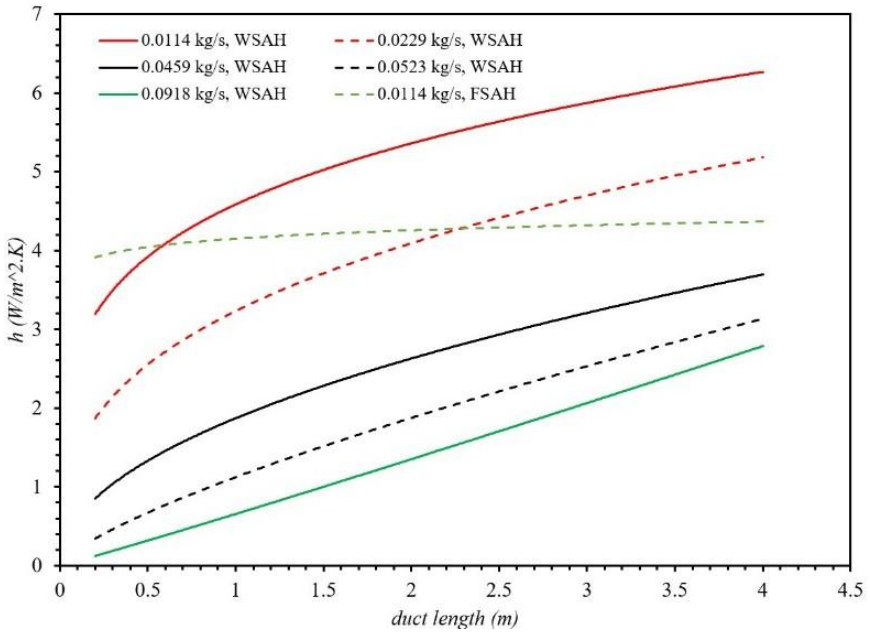


Fig. 3. Mass flow rate effect on convective heat transfer coefficient

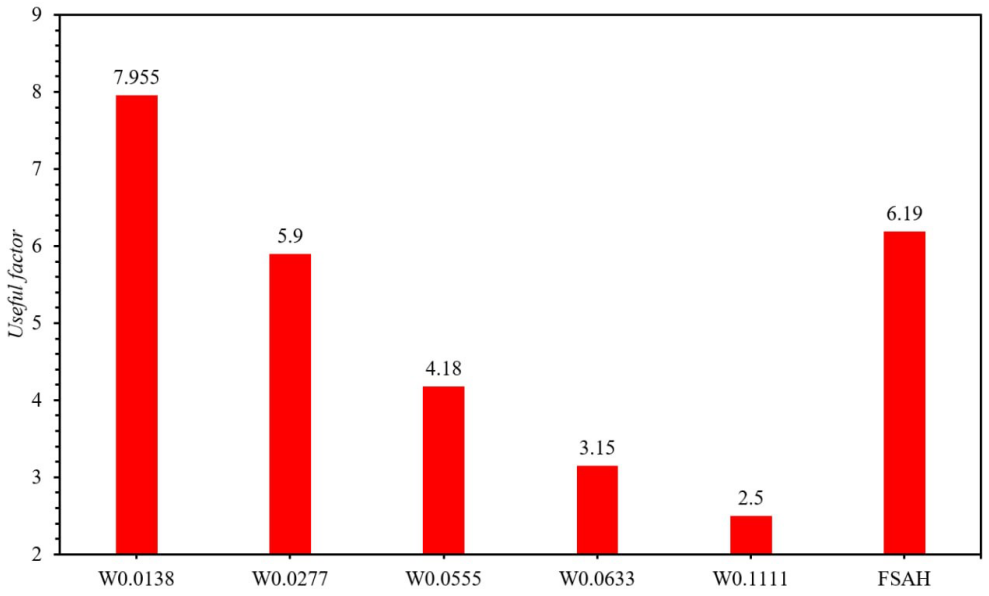


Fig. 4. Mass flow rate effect on useful factor for each SAH type

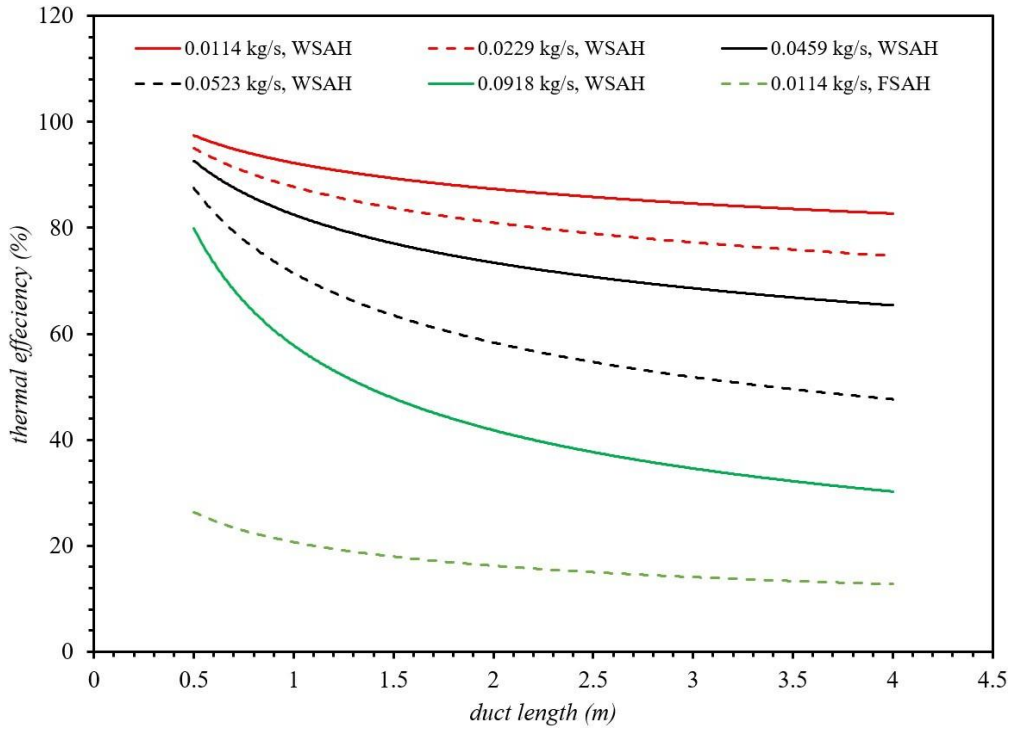


Fig. 5. Mass flow rate effect on thermal efficiency along the duct

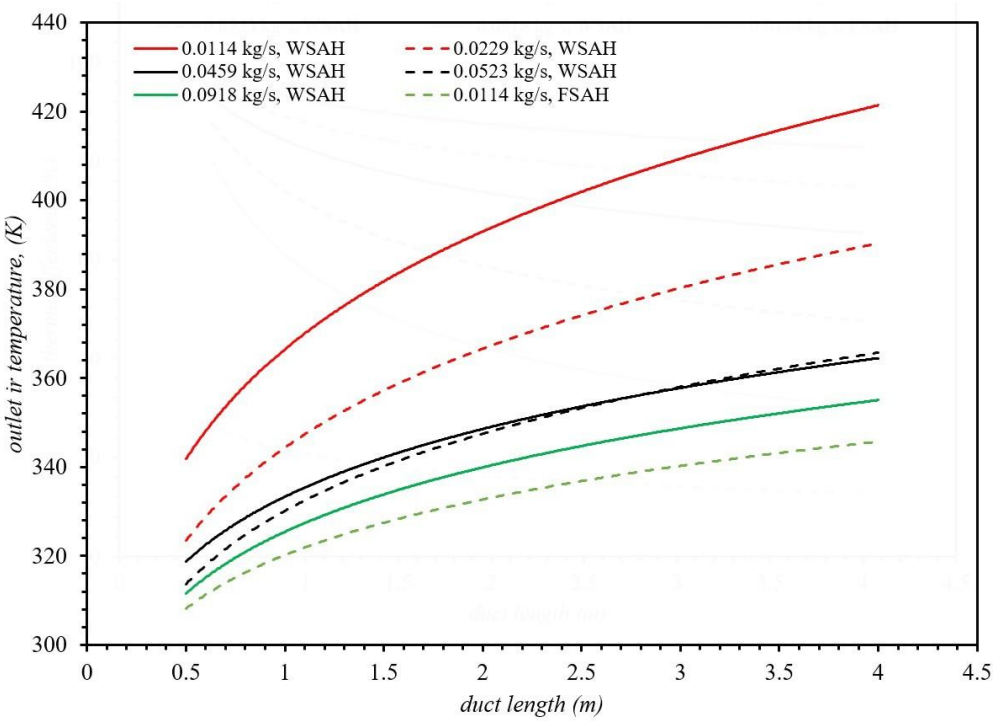


Fig. 6. Outlet air temperature according to each mass flow rate along the duct

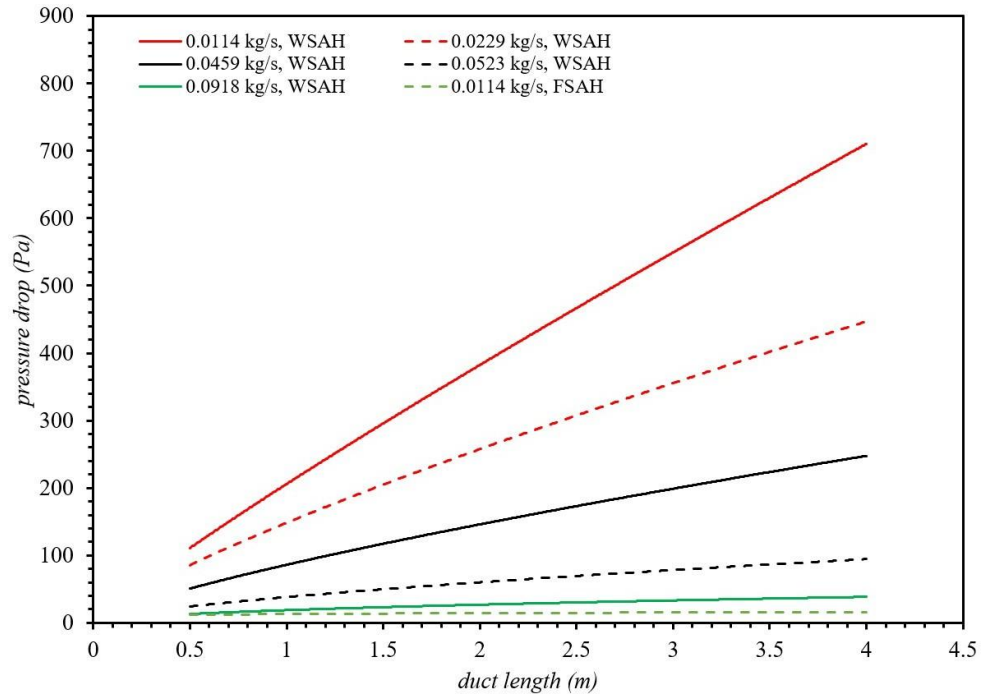


Fig. 7. Effect mass flow rates on pressure drop along the duct

4. Conclusions

ANSYS FLUENT R2024 was used to acquire heat transmission and pressure-reducing characteristics of the SAH with curvy fins, as well as the effect of SAH extension. The following lists the key findings from the data:

1. Under every mass rates of flow, as the collector length grows, so does the pressure drop along the collection. (ΔP) for the curved fin SAH is 6.01% at a lower mass air flow rate of 0.0114 kg/s for a SAH length of 0.75 m, and it rises to 19.4% over the SAH long of 6 m.
2. As collection length grows, outlet temperature rises as well. Additionally, for the curvy fins SAH, increasing the SAH length was inefficient above the mass flow rate of 0.045 kg/s.
3. With a range of 0.2 m to 4 m, the SAH length causes a drop in thermal efficiency. A less severe decline has been observed for longer collector lengths, exceeding 1.15 meters.

Nomenclature

A_c	Collector area (m^2)
A_{fr}	Minimum free flow area (m^2)
amp	Amplitude of curvy fin (mm)
A_p	Area of absorber plate (m^2)
A_r	Total heat transfer area (m^2)
C	Constant (defined by equation 4)
C_p	Specific heat at constant pressure (J/kg.K)
D_h	Hydraulic diameter (m)
f'	Constant used to evaluate top loss coefficient
H	Spacing between absorber plate and bottom plate (m)
h_e	Effective heat transfer coefficient ($W/m^2.K$)
h_f	Height of fin (m)
h_{ff}	Convective heat transfer coefficient between air to air($W/m^2.K$)
h_{fp}	Convective heat transfer coefficient between air and absorber plate(W/m^2K)
h_r	Radiative heat transfer coefficient($W/m^2.K$)
h_w	Wind heat transfer coefficient ($W/m^2.K$)
I	Intensity of Solar radiation (W/m^2)
k_a	Thermal conductivity of air (W/m.K)
k_{GI}	Thermal conductivity of G.I sheet (W/m.K)
ki	Thermal conductivity of insulating material (W/m.K)
L	Length of the collector/ Absorber plate (m)
L'	Actual length of curved fin (m)
n	Number of fins
N_{gc}	Number of glass covers
p	Porosity
Q_u	Useful thermal energy gain (W/m^2)
S	Absorbed Solar Energy, $I(\tau\alpha)_e$ (W/m^2)
T_a	Ambient Temperature (^oC)
T_{fi}	Inlet air temperature (^oC)
T_{fo}	Outlet air temperature (^oC)
T_{pcal}	Calculated Mean plate temperature (K)
T_{pm}	Mean plate temperature (K)
T_{sky}	Sky temperature (K)

U_b	Bottom loss coefficient (W/m^2K)
U_L	Total loss coefficient (W/m^2K)
U_t	Top loss coefficient (W/m^2K)
v	Average air velocity (m/s)
V_w	Wind velocity (m/s)
w	curvy fin spacing (cm)
W	Width of the collector/ Absorber plate (m)
δ_f	Thickness of fin (m)
Re	Reynolds number
Pr	Prandtl number
Nu	Nusselt number
j	Colburn j -factor
f	Friction factor
F'	Collector efficiency factor
FR	Collector heat removal factor
SAH	Solar air heaters
$\dot{m}_a$	Air mass flow rate (kg/hr)
ΔP	Pressure drop (N/m^2)
ρ	Density of air (kg/m^3)
θ	Collector tilt angle (◦)
σ	Stefan-Boltzmann Constant ($5.67*10^{-8}$ W/m^2K^4)
ε_C	Emissivity of glass cover (0.88)
η_{eff}	Effective efficiency
η_f	Fan efficiency (0.65)
δ_i	Thickness of insulation (m)
ε_P	Absorber plate emissivity (0.95)
λ	Wavelength of curvy fin (mm)
Φ_f	Fin efficiency

References

[1] Duffie J.A, Beckman W.A. (1980). *Solar Engineering of Thermal Processes*, Wiley, New York.
[2] Krieder J.F, Krieth. (1978). *Principles of Solar Engineering*, 2nd Edition, McGraw Hill Book Company, New York.
[3] Biondi, P., L. Cicala, and G. Farina. "Performance analysis of solar air heaters of conventional design." *Solar Energy* 41, no. 1 (1988): 101-107. https://doi.org/10.1016/0038-092X(88)90120-X
[4] Choudhury, C., and H. P. Garg. "Design analysis of corrugated and flat plate solar air heaters." *Renewable energy* 1, no. 5-6 (1991): 595-607. https://doi.org/10.1016/0960-1481(91)90003-8
[5] Choudhury C., Andersen S.L., Rekstad J. (1988). A SAH for low temperature applications, *Solar Energy*, Vol. 40, No. 4, pp. 335-43. https://doi.org/10.1016/0038-092X(88)90006-0 .
[6] Joudi K.A., Mohammed A.I. (1986). Experimental performance of a SAHwith a ''V'' corrugated absorber, *Energy Conversion and Management*, Vol. 26, No. 2, pp. 193- 200. https://doi.org/10.1016/0196-8904(86)90054-3
[7] Ghodbane, M., B. Boumeddane, N. Moummi, S. Largot, and H. Berkane. "Study and numerical simulation of solar system for air heating." *Journal of Fundamental and Applied Sciences* 8, no. 1 (2016): 41-60. https://doi.org/10.4314/jfas.v8i1.3
[8] Tanda, Giovanni. "Performance of solar air heater ducts with different types of ribs on the absorber plate." *Energy* 36, no. 11 (2011): 6651-6660. https://doi.org/10.1016/j.energy.2011.08.043
[9] Karim M.A., Hawlader M.N. (2005). Performance evaluation of a v-groove SAHfor drying applications, *Appl. Therm. Eng.*, Vol. 26, No. 1, pp. 121-30. https://doi.org/10.1016/j.applthermaleng.2005.03.017
[10] Yildiz, Cengiz, Inci Turk Togrul, Celal Sarsilmaz, and Dursun Pehlivan. "Thermal efficiency of an air solar collector with extended absorption surface and increased convection." *International communications in heat and mass transfer* 29, no. 6 (2002): 831-840. https://doi.org/10.1016/S0735-1933(02)00373-1
[11] Youcef-Ali, Sabri. "Study and optimization of the thermal performances of the offset rectangular plate fin absorber plates, with various glazing." *Renewable Energy* 30, no. 2 (2005): 271-280. https://doi.org/10.1016/j.renene.2004.04.009

[12] Youcef-Ali, S., and J. Y. Desmons. "Numerical and experimental study of a solar equipped with offset rectangular plate fin absorber plate." *Renewable energy* 31, no. 13 (2006): 2063-2075. https://doi.org/10.1016/j.renene.2005.10.008

[13] Shaw D., Priyam A., Singh R.K. (2015). Thermohydraulic performance of SAH equipped with curved fin absorber plate, ICAER-2015; IIT Bombay: 15-17 Dec'15.

[14] Marletta, Luigi, and Gianpiero Evola. "Thermodynamic analysis of a hybrid photovoltaic/thermal solar collector." *International Journal of Heat and Technology* 31, no. 2 (2013): 135-142. https://doi.org/10.18280/ijht.310218

[15] Vinod P.D., Singh S.N. (2017). Thermo-hydraulic performance analysis of jet plate SAHunder cross flow condition, *International Journal of Heat and Technology*, Vol. 35, No. 3. https://doi.org/10.18280/ijht.350317