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Experimental Investigation of Pre-Heating Double Pass Flow Arrangement On Thermal Performance Enhancement of Evacuated Glass-Thermal Absorber Tube Collector (EGATC) For Air Heating Application

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ABSTRACT

Thermal energy storage (TES) in solar thermal application assist in increasing the performance and efficiency of the solar thermal collector system. Various technique has been developed to enhance TES performance, such as using water and PCM as energy storage material. The type of material selection and design arrangement also contributes to the performance of solar thermal collector systems. This research aims to enhance the thermal performance of the outlet temperature of an Evacuated Glass-Thermal Absorber Tube Collector (EGATC) for air heating applications. The performance study has been conducted to measure the outlet temperature per indoor setup under the artificial solar radiation on the parameter effect of double pass flow arrangement with pre-heating inner absorber parameter. The comparison experiment at wind speed 0.9 m/s for stainless steel inner absorber showed better results on temperature outlet 47.7°C, energy store 4.46KJ and efficiency (collector + storage) 37.5% compared with insulation materials internal absorber with temperature outlet 44.7°C, energy store 4.40KJ and efficiency (collector + storage) 31.1%, respectively. This concluded that EGATC performance can be increased with those respective parameters.

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1. Introduction

According to (Chamoli et al., 2012), several ways to enhance the heat transfer rate at the thermal absorber were eliminating the interruption of the unchanged fluid velocity, eliminating the existing laminar sub-layer at the turbulent boundary layer, and implementing of secondary heat transfer surface. The concept of implementing a secondary heat transfer surface means doubling up the surface area contact (to maximize heat extraction from the absorber) in a similar drying chamber (to minimize heat losses) which created pre-heating flow without an increase in the system cost (Mohamad, 1997). This design arrangement resulted in higher thermal efficiency for double-pass solar air heaters (Singh et al., 2019). (Salih et al., 2019) The agreed double pass flow solar air heater (DPSAH) produced higher efficiency when the system was operated under natural convection case compared to the forced convection case.

There were various studies on double pass flow with regards to solar air heaters by (Omojaro & Aldabbagh, 2010), (El-Sebaii et al., 2011), (Ho et al., 2012), (Krishnananth & Kalidasa Murugavel, 2013), (Nowzari et al., 2014), (Nowzari et al., 2015), (Singh & Dhiman, 2016), (Alam & Kim, 2017), (Heydari & Mesgarpour, 2018), (Sajawal et al., 2019), (Singh, 2020) and (Sharol et al., 2020). These studies discussed the same findings that double passes achieve better performance than single-pass solar air heaters. This was due to a higher heat transfer coefficient by increased surface area contact between air and thermal absorber which increased the heat transport from the thermal absorber to heat transfer fluid and reduced the losses from the collector surface as well (Satcunanathan & Deonarine, 1973). However, further enhancement can be expanded by the flow redirection method where air in-flow at the thermal absorber was diversified using diversion of the airflow path.

This study aims to enhance the thermal performance of EGATC on outlet temperature. Various factors influence the thermal performance of EGATC. However, the current study focuses on investigating pre-heating double pass flow arrangement for EGATC to increase thermal performance. To the authors' best knowledge, the effect of pre-heating double pass flow arrangement on the thermal absorber inside an evacuated glass has not been investigated. The reports available in the literature only focuses on typical solar air heaters. The findings may also deliver beneficial information on the performance enhancement of the EGATC systems.

2. Methodology

The solar thermal collector used was known as an Evacuated Glass–Thermal Absorber Tube Collector (EGATC) as per reported (Zakaria et al., 2021) in the previous study. The thermal absorber was divided into two (2) parts i.e., outer absorber and inner absorber. The outer absorber consists of a large diameter stainless-steel pipe closed by one side end cap, while in this study, the inner absorber consists of a small diameter made of stainless steel and insulation material pipe attached with zero (0) perforated fins. Both outer and inner absorbers were integrated inside the evacuated glass.

Insulation material made from Polyvinyl Chloride, also called PVC, was a thermoplastic material. PVC was very versatile and was a widely known and used compound. PVC had a good combination of characteristics, so it was so commonly used for wire insulation and cable jacketing. PVC was flexible, durable, UV resistant, and highly resistant to chemicals, water, and fire within its nominal temperature ratings between -20°C and 105°C. This Industrial Grade PVC type of material was used to replace the stainless-steel inner absorber to prove whether a double pass flow arrangement with pre-heating occurring inside the inner absorber was able to enhance the thermal performance.

The pre-heating double pass flow experiment was conducted as an indoor experiment (Figure 1) by monitoring the outlet temperature between zero (0) perforated fin EGATC (with the specification of zero (0) perforated fin, non-coating stainless-steel inner absorber, non-coating outer absorber with 1mm wall thickness) and zero (0) fin (insulation material inner absorber) EGATC (with the specification of zero (0) perforated fin, insulation material inner absorber, non-coating outer absorber with 1mm wall thickness).

Figure 1. d The Pre-Heating Experiment of Zero (0) Fin (Insulation Material Inner Absorber) EGATC During Charging and Discharging

Meanwhile, Figure 2 shows the insulation material and stainless-steel inner absorber without a perforated fin. The pre-heating experiment was conducted with a similar arrangement, devices, and apparatus to the previous parameter experimental setup studied Zakaria et al. (2022).

Figure 2. d The Insulation Material and Stainless-Steel Inner Absorber Without Perforated Fin

3. Thermal Energy Storage and Efficiency

As per assumption, the study was considered as a closed system, without wind and no elevation change. The collector heat transfer rate was expressed as (Fudholi et al., 2015) (Duffie & Beckman, 2013):

$$\dot{Q}_{Collector} = \rho A v C_{p(air)}(T_o - T_i) \text{ ....(1)}$$

Equation 1 was used to convert energy from solar radiation into heat to increase the outlet temperature of the collector by referring to the inlet temperature. While Equation 2 was used to calculate energy from solar radiation and converted into energy storage at the thermal absorber by referring to instantaneous energy accumulation for each second. The heat transfer rate of the thermal absorber storage was expressed as (Fudholi et al., 2015) (Duffie & Beckman, 2013):

$$Q_{Store} = \frac{m_{ab}C_{p(ab)}(T_2 - T_1)}{t_2 - t_1} \text{....................................(2)}$$

Thus, the collector and storage efficiency of the system was expressed as:

$$\eta_{Collector+Storage} = \frac{\dot{Q}_{Collector} + Q_{Store}}{G_t A_c} \times 100\% \text{....................................(3)}$$

By resolving Equation 1 and Equation 2 into Equation 3, the efficiency of the collector and storage was expressed as:

$$\eta_{Collector+Storage} = \frac{\rho A v C_{p(air)}(T_o - T_i) + \left(\frac{m_{ab}C_{p(ab)}(T_2 - T_1)}{t_2 - t_1}\right)}{G_t A_c} \times 100\% \text{....................................(4)}$$

Where

ρ	=	Density of air (kg/m^3)
A	=	Area of inlet duct (m^2)
v	=	Velocity of air at inlet duct (*m*/*s*)
$C_{p(air)}$	=	Specific heat of air (kJ/kgK)
T_o	=	Air outlet temperature (K)
T_i	=	Air inlet temperature (K)
G_t	=	Global solar radiation ($Watt/m^2$)
A_c	=	area of collector (m^2)
m_{ab}	=	mass of thermal absorber (kg)
$C_{p(ab)}$	=	Specific heat of thermal absorber (kJ/kgK)
T_2	=	Temperature of thermal absorber after heat gain (K)
T_1	=	Temperature of thermal absorber before heat gain (K)
t_2	=	Time after heat gain (s)
t_1	=	Time before heat gain (s)

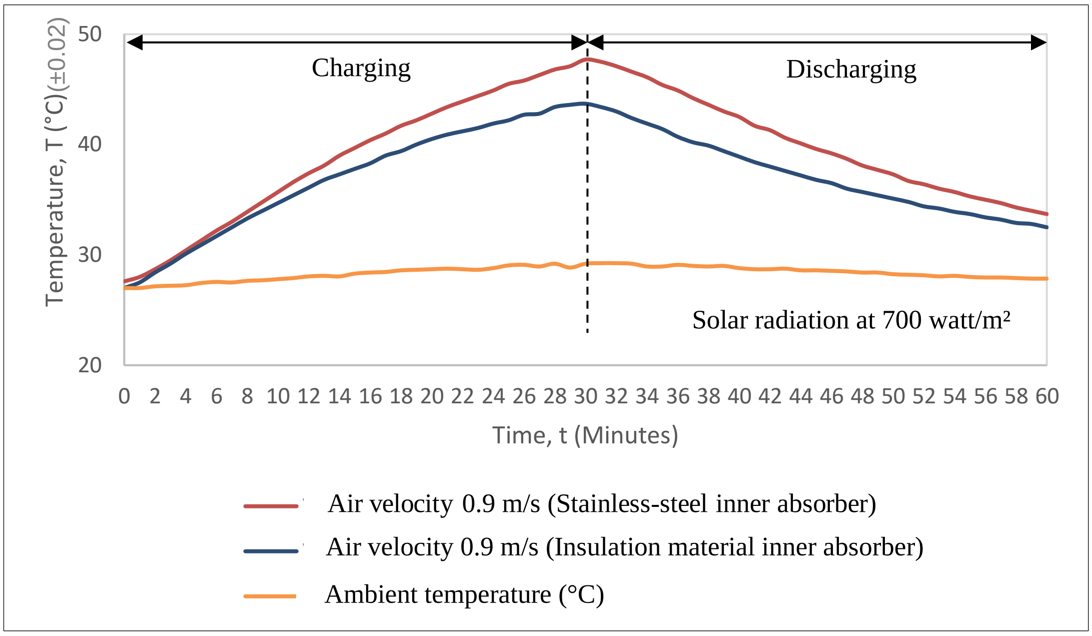

Figure 3. Outlet Temperature Histories Between Stainless Steel Inner Absorber and Insulation Material Inner Absorber for Pre-Heating Experiment

The pre-heating experiment was conducted to prove whether a double pass flow arrangement with pre-heating occurred inside the inner absorber able to enhance the thermal performance. From the result, zero (0) perforated fin with a stainless-steel inner absorber EGAT showed the better result (Figure 3) regarding of outlet temperature.

After 30 minutes of charging, the outlet temperature of zero (0) perforated fin with stainless-steel inner absorber EGATC was 47.7°C compared with zero (0) fin with insulation material inner absorber 44.7°C with differences of 3°C. In term of energy store, Q_{Store}, the stainless-steel inner absorber also had an advantage with 4.46kJ compared to the insulation material inner absorber 4.40 kJ. At the end of discharging period at minutes 60, the outlet temperature of both inner absorbers was 33.7°C and 33.5°C, respectively. With differences in outlet temperature between minutes 30 and minute 60 for the stainless-steel inner absorber 14.0°C, and insulation material inner absorber 11.2°C affected the energy buffer for both inner absorbers, -0.00778°C/s and -0.00622°C/s respectively. Table 1 shows the calculated values obtained from the experiment.

Table 1. The Calculated Values Obtained from The Pre-Heating Experimental Runs

No.	Optimization Parameters	$\dot{Q}_{Collector}$ (KJ) (±0.002)	Q_{Store} (Daily) (KJ) (±0.002)	Tout @ mins 30 (°C) (±0.02)	Tout @ mins 60 (°C) (±0.02)	Temp. different (°C) (±0.002)	Energy buffer (°C/Sec) (±0.000002)
1	0 Perforated Fin EGATC (V=0.9 m/s) (Stainless steel Inner Absorber)	23.23	4.46	47.7	33.7	14.0	-0.00778
2	0 FIN (Insulation Material Inner Absorber) EGATC (V=0.9 m/s)	18.53	4.40	44.7	33.5	11.2	-0.00622

Due to the analysis, Table 2 shows the result between zero (0) perforated fin EGATC with stainless steel inner absorber and zero (0) perforated fin with insulation material inner absorber involved in the parameter experiment. This experiment also was conducted with a similar arrangement to previous parameters experiments.

Table 2. The Parameter Experimental Result Between Zero (0) Perforated Fin EGATC with Stainless Steel Inner Absorber and Zero (0) Perforated Fin with Insulation Material Inner Absorber

No.	Optimization Parameters	Gt hour per day (hour) (±0.002)	Vair (avg) (m/s) (±0.02)	E($GtAc$) (kJ) (±0.002)	E ($\dot{Q}$ $Collector$) (kJ) (±0.002)	Efficiency (collector) (%) (±0.02)	Q_{Store} (Daily) (kJ) (±0.002)	Efficiency (collector + storage) (%) (±0.02)
1	0 Perforated Fin EGATC (V=0.9 m/s) (Stainless steel Inner Absorber)	0.71	0.9	73.79	23.23	31.5	4.46	37.5
2	0 FIN (Insulation Material Inner Absorber) EGATC (V=0.9 m/s)	0.71	0.9	73.79	18.53	25.1	4.40	31.1

5. Conclusion

The study on outlet temperature proved better thermal performance enhancement of EGATC. The analysis was carried out with consideration of artificial solar radiation, through indoor experiments. Based on the experimental result and analysis, several discussions were made, as followed:

- Zero (0) perforated fin with stainless-steel inner absorber EGATC showed a better outlet temperature result than zero (0) fin with insulation material inner absorber. This stainless-steel inner absorber EGATC consists of conductive inner absorber material that affected the math and the total absorber's marble pass arrangement. These were the main factors that initiated the initial heat convection (also known as pre-heating) inside the inner absorber before the airflow moved toward the other user absorber. According Vengadesan & Senthil (2020), to the metal matrix and packed bed porous thermal absorbers were recognized as an effective way to increase the temperature distribution of air. It also acted as heat storage material as it stores maximum heat from the thermal absorber, and it can be efficiently transferred to the air due to the increased contact area between air and thermal absorber. Regarding the number of fins, Zakaria et al. (2023) had concluded that the efficiency depends on the number of fins. The more the fins, affect the lower the collector and storage efficiency.
- The pre-heating air flow moved toward the outer absorber and produced the cumulative heat gained inside the outer absorber thus doubling up the temperature at the outlet. The mass flow rate will be higher at higher temperatures due to the higher density gradient (Ling et al., 2015). The types, mass, and arrangement of the conductive inner absorber material showed that the double pass with pre-heating arrangement inside EGATC was significant. (Vengadesan & Senthil, 2020) had concluded that the implementation of obstacles on the thermal absorber was the main factor in evolving the airflow path to increase the heat transfer area and time. An obstruction such as a perforated fin was preferred over the plain, as the airflow velocity increased over the holes. Hence, the secondary flow occurred, which moved towards the main flow for complete fluid mixing.

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