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ENERGY CONVERSION OF V-CORRUGATED ABSORBER PLATE SOLAR AIR HEATER WITH PHASE CHANGE MATERIAL

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Abstract- The solar collector is one of the significant passive solar energy usages. Phase change material (PCM) has been used in experiments to test the efficiency of the standard solar air heater's V-corrugated absorber portion. Paraffin wax phase transition material has been utilized with solar air heaters as a storage method of thermal energy. The highest convection heat transfer for heat discharge throughout the night and the absence of solar radiation was present as a latent heat. It was conducting with keeping constant of all dimensions for the two collectors under 0.013 kg/s flow rate and Iraq climatic conditions (36.348°N, 43.1577°E). The results indicated that the performance of V-corrugated absorber plate solar collector is 63.2% as compared to the classical heater which is 29.2% during April 2021. It was illustrated that the modified solar collector outlet temperature is increased as compared the classical collector. The maximum difference of air temperature inlet and outlet collector were 17.6°C and 26.5°C for the V-corrugated absorber plate solar heater respectively. The V-corrugated absorber plate solar collector was shown to increase thermal efficiency and improve exit air temperature while lowering heat loss.

Keywords: PCM, Performance; Solar Air Heater; Solar Energy; V-Corrugated Absorber Plate.

1. INTRODUCTION

In order to harness the sun's thermal energy, a solar air collector is used [1]. In most cases, a solar collector will act as a heat exchanger, by heating the air as it is circulated inside it. The solar collector as a heating application thermal performance has been affected by different variables as the solar radiation amount that reaches the heater surface, the shape and size of the absorption area, the design and orientation of the heating system, the air temperature upon entry, and the air's velocity as it flows within the heater. At mild to chilly temperatures, solar collectors are a common source of renewable energy [2, 3]. Benefits such as inexpensive initial investment, low operating costs, and enhanced indoor air quality more than make up for its low efficiency.

In Baghdad, Rashid and Saleh [5] evaluated the heating effectiveness of five different designs for single-pass solar air heating devices through a combination of experimentation and computational approach. The conventional flat plate solar collector, finned absorber plate solar collector, the flat plate solar thermal system with an iron wire mesh, the corrugated absorbed energy plate solar collector and the collector for solar energy with a flat plate with a porous medium on top were all considered. In the tests, 0.016 to 0.019 kg/s different rates of air mass flow were used. The results showed that the porous medium solar heating collector had a 56% efficiency, with the wire grid heater coming in at a distant second with a 51% rate of effectiveness. The waved sheet solar collector was 34% efficient, whereas the finned heater was 30% efficient. The traditional heater was the least efficient, with a 26 percent efficiency. In a study, Wang et al. [6] constructed S-shaped ribs and gaps on the absorber plate to lower circulation resistance and therefore boost the effectiveness of a single-pass solar heater.

The investigators claim that by enabling improved heat transport between the air and the plate that absorbs heat, this design raises the thermal effectiveness of the solar collector. According to the findings, adding ribs could, depending on the operating circumstances, increase the thermal efficiency by (13-48%). Studying the effects of various factors on the heating efficiency and friction factor of two double and single-pass solar collector without and with a porous medium is necessary, Bashria, et al. [7] conducted a theoretical analysis. According to the researchers' findings, a double-pass solar collector has thermal efficiency that is 10–20% higher than a single heater collector, and using porous material increases thermal energy by up to 8%. Foil and gravel porous substance was augmented a double pass solar collector system's bottom passage, Kumar and Singh [8] compared a conventional single-pass photo voltaic heater to the latter.

The upgraded system with the porous material achieved a 67 percent efficiency at the same operating temperatures, compared to a traditional system's 49 percent efficiency. Because of the of porous media found, which serve to retain heat and thus modified the performance, the quantity of energy lost through the double-pass heating system is substantially smaller. The collector, particularly around the absorber plate, was blamed for the differences in heat loss, according to the researchers. To explore how porous media (steel wool and glass wool) impacted the solar collector efficiency, Gupta, et al. [9] evaluated a conventional single-pass air heater to a double-pass solar air collector. The investigators illustrated that porous media have a high Nusselt number and a large surface area for heat transfer, that improves thermal efficiency. The experiment's findings further showed that the air mass flow rate has an impact on the solar energy heater thermal performance, with thermal performance growing as air mass flow increases. When compared to a traditional single-pass solar air collector, using steel wool for a double-pass solar heat collector enhances thermal efficiency by 40.23%, while utilizing glass wool improves thermal efficiency by 33.1%.

Mahmood [10] examined the effects of baffles connected to wire layers of baffles on the dependability as well as the effectiveness of a solar air collector in an empirical study. However, the highest temperature difference was obtained at an airflow of 0.011 kg/s, seven layers of baffles, and a depth of 3 cm for the lower layer. A double-pass solar air heating system with 7 baffle layers and an airflow of 0.032 kg/s and a depth of 3 cm for the bottom access obtained the best thermal efficiency. The impact of three different solar heater of thermal performance on the quantity and fins height that installed on the absorber plate is examined in a theoretical study by Fudholi, et al. [11]. The first kind is a double-pass solar heater with bottom and top longitudinal fins, but the other has lower longitudinal fins, and the third has both types. The efficiency of a heater, according to the study, rises with fin height and count. The efficiency of air heaters powered by solar energy increases by 36-73% for top fins, 34-38% for bottom fins, and 45-75% for combined upper and lower fins when the mass discharge is between 0.03 to 0.1 kg/s.

A solar collector's performance can be enhanced by adding corrugated fins to the fluid medium flowing beneath the absorber plate, claim Kumar et al. [12]. The balance equation of energy of the unique design solar collector is used to construct and resolve a computational model in MATLAB. When the pitch of fin is two centimeters at a constant mass discharge of 0.026 kg/s, the thermal performance of a conventional solar heater rises from 35 percent to 55 percent, but at an additional cost of a larger pressure drop, which was justified by "effective or thermos-hydraulic efficiency". In this article, we want to see how the solar collector performance changes when a corrugated steel wool and absorber plate are added to the bottom pass with PCM for thermal energy storage. We will do this under different conditions, such as the amount of sunlight hitting the collector and the air temperature around it during winter season in Mosul, Iraq.

2. GOVERNING EQUATIONS AND CALCULATION

Thermal efficiency (η) is the ratio of useful power to the total amount of solar energy absorbed at a specific time. and can be evaluated as [13]:

$$\eta = \frac{Q_u}{IA_c} \tag{1}$$

where, the solar heater useful heat gains (Q_u) are the difference between the solar heater lost and the amount of incident radiation (heat received) whereas, (I) the solar radiation received per unit area (A_C). The received heat of the solar air collector is estimated by Equation (2) [13]:

$$Q_i = I.A_c \tag{2}$$

Because the absorber plate heats up when a solar heating system uses sunlight to generate heat, some of the energy will be dissipated into the atmosphere. The solar air collector heat loss (Q_o) is influenced by the air temperature entering the system additionally, the overall heat transfer (U_L) [13]:

$$Q_o = U_L A_c (T_p - T_a) \tag{3}$$

The useful heat gain at the steady-state thermal equilibrium equation is represented the difference between the heat loss of solar air collector and the amount of heat gain as [14]:

$$Q_u = Q_i - Q_o \tag{4}$$

$$\eta = (\tau\alpha) - U_L \frac{T_p - T_a}{I} \tag{5}$$

The efficiency may be evaluated as following due to the useful heat gain from solar intensity which is equal the heat gains the air passing through the heater [14]:

$$\eta = \frac{\dot{m} C_p \left(T_p - T_a\right)}{IA_c} \tag{6}$$

The overall heat transfer coefficient may be evaluated as [14]:

$$U_L = \frac{Q_o}{IA_c \left(T_p - T_a\right)} U \tag{7}$$

3. EXPERIMENTAL TEST

3.1. Test Rig.

The two solar air collector's system with a double pass has been fabricated. The first one is a regular solar collector which was named a standard collector and the second heater is an enhanced solar heater which is named as a modified collector. The modified solar collector contained of a corrugated absorber sheet that has a 60-degree "V" angle. Paraffin wax phase change material has been utilized with solar collector system. During the night and no solar radiation, the latent heat was present as a maximum convective heat transfer for discharging heat, PCM materials thermal properties are indicated in Table 1.

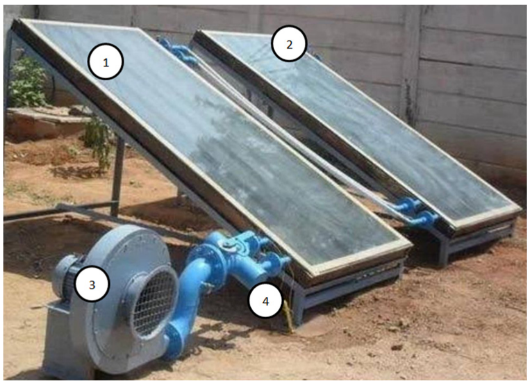
Table 1. PCM materials properties [12]

Comp.	ρ (kg/m^3)	k (W/m °C)	Cp (kJ/kg)	Melting temperature (°C)
Paraffin-wax	789 (liquid, 60 °C) 915 (solid, 22 °C)	0.159 (liquid, 54 °C) 0.352 (solid, 34 °C)	172.7	52
Polyglycol E 600	1119 (liquid, 25 °C) 1233 (solid, 5 °C)	0.192 (liquid, 36.8 °C)	126.8	23

The two systems were fabricated using components sourced from the materials that were readily available on the market in the area. The framework of both of these systems was constructed out of 1.8 cm plank wood, and the top cover for both of these systems was made out of glass with a thickness of 6 millimeters. A 2 cm foam insulation is fixed so that there would be less heat removal from the bottom and sides of two systems. It was made out of an aluminum alloy 1060-H16, and it had a thickness of 0.8 millimeters. Both of the heaters' absorber plates were painted with a black paint that had a greater thermal conductivity rating (ETIKA). Comparatively, the graded plate had an area of 3.88 m^2 whereas the flat absorber plate had an area of only 2 m^2. The lower channel was filled with steel wool in an amount that was sufficient to fill it (10 cm width, 7.5 cm height and 2 m length per channel).

A power of 3.6 W for each heater were fitted to draw air through the system and 3 DC fans with a 0.3 A capacity of each fan. When a fan's propellant force is connected to a control device, it can modify the pace and amount of air that is pumped into the system as shown in Figure 1. The thermocouple Type K with 0.4 mm diameter was employed to measure temperature. It was placed after a special welding machine fastened its outer end to the heater's glass cover with three points (lower, top, and middle), additionally, three locations on the absorber plate and for the upper and lower channels. It was installed two thermocouples to read the air temperature getting into and out of the solar collector, which was secured with adhesive materials [15].

In order to compare the thermocouple reading with the solar meter recording and determine the accuracy, a total of fifteen electronic components pieces are used, including the SM 206 solar meter, GM 816 anemometer, voltage meters, and a thermometer. The thermocouple's low voltage has been converted into a voltage that may be read by the Arduino piece using fourteen components for each system. With the help of an Arduino-type processor (the MEGA 2560), we can now input temperature values into an Excel spread sheet.



1) Corrugated plate, 2) Flat plate, 3) Blower, 4) Valve

Figure 1. Test rig. and system

The thermocouples are linked to the Max 6675 electronics, the Mega 2560 Arduino, and the computer. The two systems share a single 12-volt DC battery and are regulated by a single on/off switch attached to the system's control circuit. We used a navigation system to point the two air heaters with solar panels south after mounting them on a base (the bearing) built at a 55° inclination for four months (15 December, 10 January, 15 February, and 10 March). And by using code written expressly for the task of logging data from thermocouples into a computer using the Arduino technique. We were also able to save the readings within Excel by connecting them with QLX DAQ. While manually logging the sun radiation levels, we recorded all of the temperature data in this manner. The computer was programmed to take and save a new set of thermocouple details every 10 minutes.

3.2. Experimental Uncertainty

The parameters that impact the amount of thermal efficiency calculated by Equation (7) have been outlined [16], allowing for the estimation of the error rate connected to experimental data in advance of the test. Air temperature at the solar collector's inlet and outlet can be measured using air mass flow rate, air capacity for heat, T_{out}, and T_{in}. In addition, (Ac) stands for the airflow cross-sectional area, the solar radiation intensity (I), and the area of surface solar collector (As). Assuming no change in the air's characteristics as a result of the experimentally determined the temperature change and the mass flow rate. Detecting air velocity (GM816) and solar intensity (SM206) devices both have a 5% error rate in addition to the data error rate. The experimental thermocouple (TYPE K) has an accuracy of (0.68 to 1.9 °C percent per degree) [17]. The uncertainties estimations of parameters are summarized in Table 2.

Table 2. The uncertainties estimations

Type	T_{out} °C	$\dot{m}$ (kg/s)	I (w/m²)	η %	*Error* %
Standard	33	0.02	750	39	1.5
Modified	45	0.03	750	65	2.5

4. RESULTS AND DISCUSSION

In the climatic circumstances of Iraq (36.34 °N, 43.15 °E) for four months (15 December, 10 January, 15 February, and 10 March), a daily measuring period of 9:00 am to 5:00 pm was used to evaluate the efficiency of conventional and enhanced solar air heating systems. The measurements were taken at a 0.02 kg/s constant air mass flow rate.

4.1. Hourly Temperature Difference

Figure 2 depicts the difference of temperature between the exit and inlet air from the solar air heater on 15 December 2021, with the maximum reaching 24 °C for the modified collector at 1:00 p.m., but the highest difference for the standard heater at 1:15 P.M. and the differences values are very small at 9:00 a.m. then the difference between the conventional and modified collectors is increased with increasing solar intensity gradually. Furthermore, the temperature difference between the modified collector and the normal heater is bigger even after midday because of the corrugated absorber plate's greater absorption of heat than flat plate.

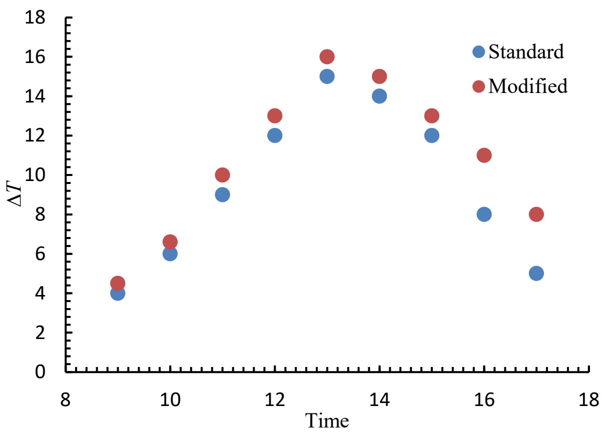


Figure 2. ΔT at 15 December 2021

Figure 3 illustrates the difference of air temperature between the two enhanced and standard collector heaters on 10 January 2022. At 1:30, the enhanced heater recorded the maximum air temperature difference of 25 °C, whereas the standard heater recorded the highest air temperature difference of 19 °C. The difference value is affected by weather conditions and solar intensity parameters. As compared to overcast or windy weather, this disparity is more pronounced on sunny days [18]. It can be seen, the temperature different between the enhanced and the regular heater increases significantly.

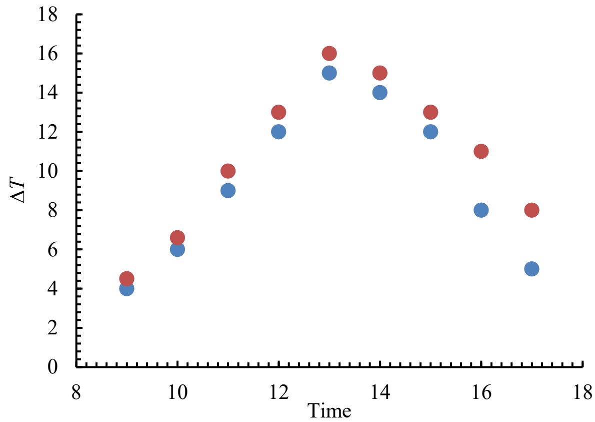


Figure 3. ΔT at 10 January 2022

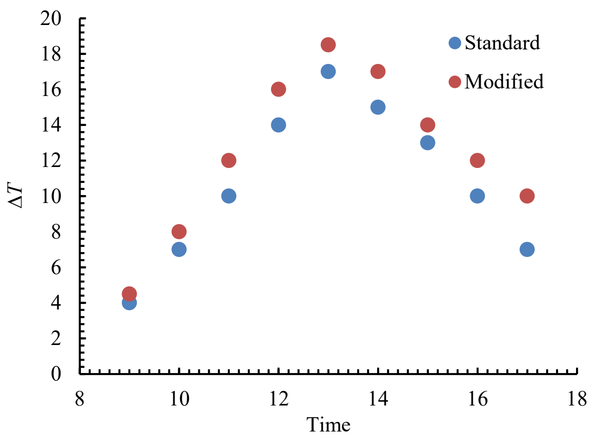


Figure 4. ΔT at 15 February 2022

Figure 4 depicts the air temperature difference on 15 February 2022. It was noted that the optimum value of the temperature of air difference for the modified collector heater is 26 °C at 1:10 with a solar intensity of 870 W/m^2. While, the maximum difference for the standard collector heater is recorded at 1:20 with the solar intensity of 866 W/m^2.

A variation in air temperature between the two heating systems can be attributed to the standard collector heater's inability to fully absorb the heat from the radiation that enters it, as opposed to the modified collector heater's ability to do so [19]. As a result, the standard collector heater responds less quickly to changes in air temperature brought on by the global solar intensity. Additionally, compared to the modified heater, the traditional heater loses more heat.

Figure 5 shows the modified collector heater largest temperature differential of 30 °C on 10 March 2022 at 1:10 p.m. The standard collector heater produced a temperature difference of 20 °C. A rise in air temperature differential between modified and standard collector heaters is noted with this difference remaining stable between 1:00 and 1:30 at the period of peak solar radiation. The difference stabilizes for a short time during this time due to the stability or little shift in the solar radiation, and then this difference declines after 2:00. The results are trend as the data of [20] which is increased of temperature deference against time for March 2020.

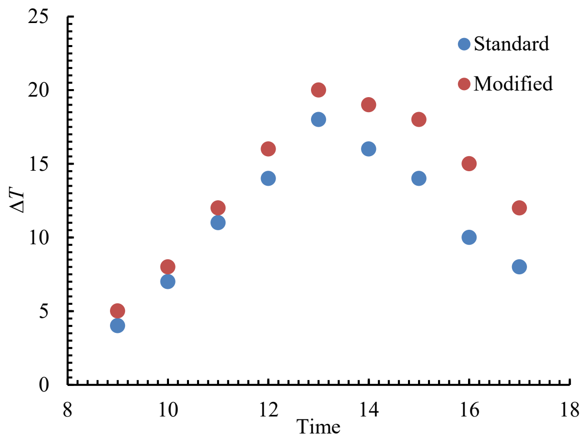


Figure 5. ΔT at 10 March 2022

4.2. Hourly Useful Heat Gain

The change in Useful gain of heat for the regular and modified solar collector heaters with incident solar radiation intensity on December 15, 2021, is depicted in Figure 6. On this day, the normal collector heater has a useful heat gain of 24 kW.hr and the upgraded collection heater has a useful heat gain of 37 kW.hr. Thus, assuming a constant air flow rate, the enhancement rate of usable gain of energy on this time is 34%.

The fluctuation of useful heat gains for regular and improved solar collectors air heaters with incident solar radiation intensity on 10 January 2022 shows in Figure 7. It was observed that the useful heat acquire by the modified collector is more than the gain of useful heat of the normal collector due to the same amount of sunlight falling and constant airflow and temperature of the two collectors. The rise in useful gain for the redesigned collector can be attributed to the addition of V- the corrugated plate, which has increased the heaters' effectiveness and efficacy [21]. The standard and modified collector heater's useful heat gains are 37 kW.hr and 48 kW.hr, respectively. It is cleared that the improvement is 11 kW.hr in useful heat gain during the reading period for that day.

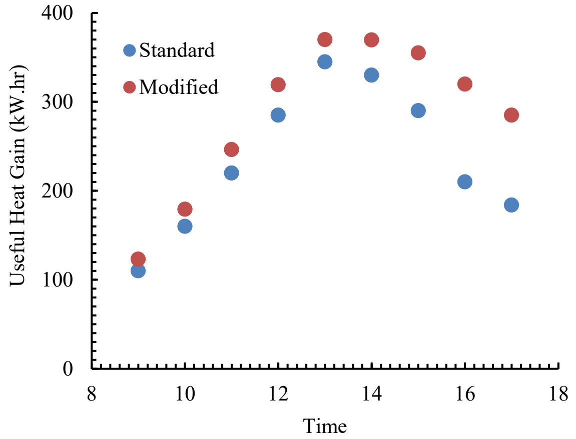


Figure 6. Useful Heat Gain at 15 December 2021

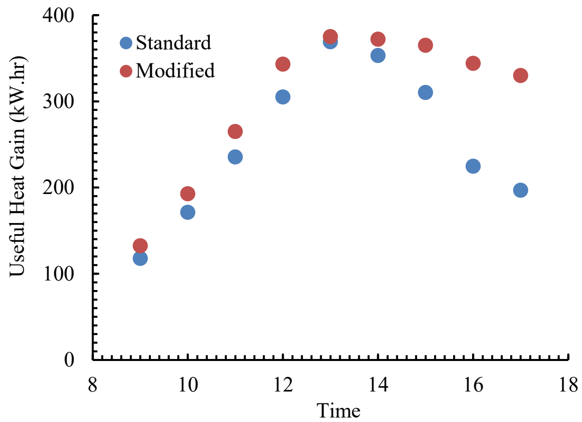


Figure 7. Useful Heat Gain at 10 Jan 2022

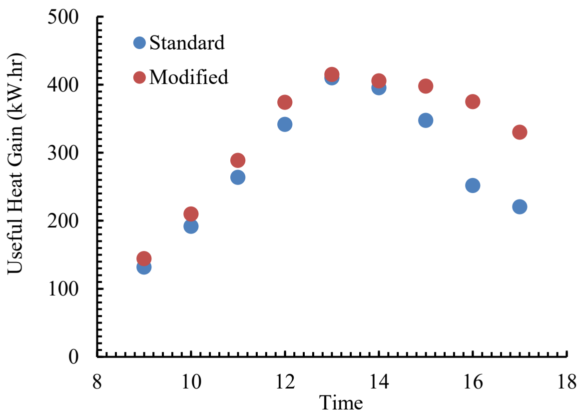


Figure 8. Useful Heat Gain at 15 February 2022

Figure 8 depicts the gain of heat useful and falling solar radiation with time during 15 February 2022. The maximum level of intensity on this time was 910 W/m^2 at 12:40, and the difference of air temperature among the air that came in and went out the modified collector heating system was 29 °C, compared to 16 °C for the normal collector heater.

This explains why the revised collector heater has a higher useable heat gain. It can be seen that the modified collector heater's useful heat gain curve path is typically similar to the solar intensity curve path, whereas the standard collector heater's heat amount curve path differs from the radiation path in many places due to the normal collector heater's higher heat loss [22]. The useful heat gains during the day for the regular collector air heater and enhanced air heater are 37 kW.hr and 20.62 kW.hr, respectively.

Figure 9 indicates changing of gain of useable heat for the two modified and conventional collector on March 10, 2022, as the strength of incident solar radiation varies throughout time. According to the graph, the heater's useful heat gain is quite substantial because March's solar radiation strength is thought to be higher than that of the other recording months. Regular collector heaters and enhanced collector heaters have average useful heat gains of 19 kW/hr and 41 kW/hr, respectively. The percentage of improvement in useable heat gain over the data from prior months is 52%.

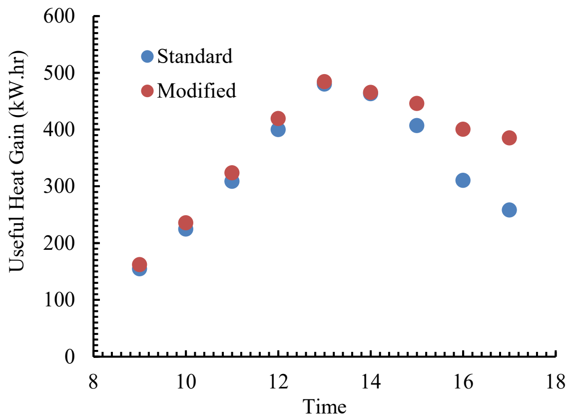


Figure 9. Useful Heat Gain at 10 March 2022

4.3. Hourly Thermal Efficiency

The thermal efficiency along daylight from 9:00 a.m. to 5:00 p.m. is depicted in Figure 10. The thermal performance of modified and standard solar collector varies throughout daylight hours due to variations in the solar radiation, which impact to the difference of temperature between the inlet and output air through the collector heaters. We can observe how much better the heating efficiency figures were for the upgraded solar collector heater on 15 December 2021 compared to the rest of the months throughout the period when the data were obtained based on absorbing solar radiation.

On January 10, 2022, a figure showing the heating performance of the two heaters over time is displayed. The figure unequivocally shows that a number of factors, such as air flow rate, temperature differences between air entering and leaving the heater, and the amount of solar radiation hitting the heater's glass cover, can affect the solar heater thermal performance. It has been discovered that thermal efficiency varies over time in tandem with variations in the strength of solar radiation. Keep in mind that the effectiveness of a 2 m^2 glass area air collection heater is affected by factors other than air temperature entering and leaving the heater [23].

The modified collector heater's thermal efficiency is 46% on this particular day, while the conventional heater is 32%, demonstrating that the modified solar air collector heater's thermal performance is 30% higher than the standard collector heater's due to enhancements to the standard heater. Furthermore, it depicts the change of the modified and standard collector heaters performance during 15 February 2022.

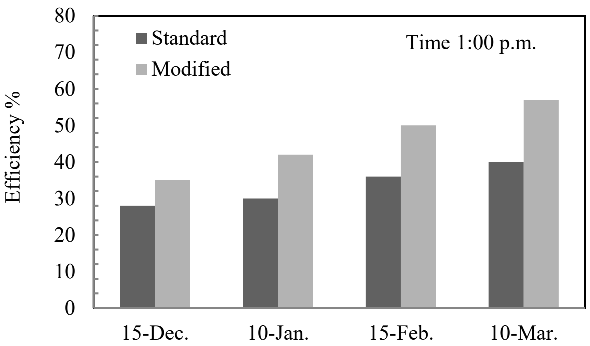


Figure 10. Thermal Efficiency for four months at time 1:00 p.m.

The modified and normal collector solar heaters' thermal efficiencies clearly differ significantly from each other. The modified collector heater's highest efficiency was 51% at 1:00 p.m., compared to the standard heater's efficiency was 38%. The percentage does not remain at a constant mass flow rate; therefore, it shifts from day to day based on the ambient and collector heater air temperatures and the sun's radiation output. It also shows how the thermal performance of the two baseline and enhanced collector heaters varies as a result of the solar radiation intensity on March 10, 2022. Its seeming rising of the rate of solar radiation this month, that contributed to a large increasing of air temperature around it, is responsible for high thermal efficiency observed this month.

The modified collector heater had a thermal efficiency of 56% on average, while the standard collector heater had a thermal efficiency of 42% on average. The figure for this month indicates a shift in the curve's shape, proving that the upgraded solar collector thermal performance keeps getting better even as solar radiation intensity gradually declines. This is because, in contrast to a standard solar collector with a constant flow rate, the amount of heat stored inside the collector is fairly considerable because of the peak period's solar radiation and the decline in outside air temperature is comparatively minor [24]. Furthermore, the flow of hot air through the solar collector minimizes energy loss and the heat transfer.

5. CONCLUSIONS

Two collectors air heaters with equal dimensions, form, and parts were experimentally fabricated in this study. The standard collector heater is consisted of flat absorber plate and the second one is modified by replacing the V-shaped corrugated absorber flat plate. The two collector heaters are tested with PCM for thermal efficiency enhancement under same weather conditions of Iraq, in order to compare their performance and efficiency.

The main conclusions of this study are summarized as:

- Paraffin wax (PCM) has a considerable use for thermal energy storage due to its low cost and rapid production of increased thermal energy.
- The modified solar collector has a better performance than the standard collector. On 10 March 2022, the enhanced heaters' daily thermal efficiency is 65 percent, whereas the standard heaters' is 31 percent. Radiation intensity and ambient temperature have a significant effect on the improvement rate, which fluctuates from month to month as well as within the same month.
- Enhanced collector air heater performance is improved by employing a V-corrugated plate to increase the absorber plate's surface area, as well as decreasing heat loss. The typical daily rate of enhancement of useful heat gain achieved 51% on March 10, 2022, as the average useful heat gain for modified and standard heaters is 41 kW.hr and 19 kW.hr, respectively.
- The air temperature exiting the modified collector air is more than the air temperature exiting the normal collector. Because the two heaters operate in the same manner, the maximum deviations between the temperature of air coming in and the air temperature coming out reached its peak on March 10, 2022, while it was 30 °C for the modified collector heater and 20 °C for the normal heater.
- The enhanced collector heater has a higher air temperature differential, useful heat gains and thermal efficiency than the standard collector heater. This proves that the changes we have made to the conventional system have been a success.

NOMENCLATURES

1. Acronyms

In Inlet
Out Exit

2. Symbols and Parameters

A: Area of solar heater (m^2)
Q: Solar air heater (kW)
I: Solar intensity (W/m^2)
C_p: Air specific heat (kJ/kg.K)
U: Overall heat transfer coefficient (W/m^2 °C)
Q_u: Useful gain of heat (kW)
η: Efficiency
$\dot{m}$: Air mass flow rate (kg/s)
ΔT: Difference of temperature (°C)
T: Temperature (°C)

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