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Thermal Performance Assessment for The Solar Air Collector Integrated with Ribs Turbulators under Nassiriya City Climate

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ABSTRACT

Analysis of heat transfer characteristics in a solar air collector was performed experimentally by using parallel ribs of different angles of attack. The ribs are perpendicular to the main flow direction. The aim of the present investigate is to determine the angle of attack that produces the best heat transmission and thermal performance in a heated duct. The rib height-to-duct height ratio (e/H) was maintained at 0.6 throughout the study. the pitch-ratio (P/e) was 10. For inclined ribs, the angles of attack (α) were altered from 30° to 90° and evaluated at a constant mass flow rate (MFR) of 0.022 kg/s, solar irradiance varied from (330 to 850) W/m^2. The hot outlet air temperature for the rib with an angle of attack (α =30°,45°, and 60°) was improved up to about 8%,14%, and 17% respectively, higher than the rib with a 90°. According to the thermal performance comparison, the rib inclined 60° provided higher Nusselt number spanning the most area when compared to the other cases.

KEYWORDS

solar air collector, ribs turbulators, heat transfer enhancement

INTRODUCTION

The contribution of this research is to enhance heat transmission and thermal performance in a heat exchanger system as it is effective field of engineering researches. Active and passive strategies for improving thermal performance are the two types of procedures available. Heat transmission is boosted in active systems by giving more energy to the fluid or equipment. Another kind is passive ways, which may be gained without the use of any external energy, such as rough surfaces(ribs) that is considered as a common technique applied in the mass transfer enhancement because the ribs interrupt flows, enhance flow mixing and turbulence, and create various secondary flows, Supattarachai et al. [1]. Many authors works have been based on thermal performance improvement, these experiments proved conclusively that using obstacles in the passage of flow raise significantly the turbulence intensity of the flowing fluid, Kumar et al. [2]. Lau et al. [3–5] With the square channel roughened with ribs that are distinct, researchers investigated the impact of rib angle of attack on average heat transfer enhancement for a wide range of Reynolds numbers. They found that the maximum average heat transfer coefficient was obtained at = 60° for the five-piece-discrete ribs and = 90° for the two-piece-discrete ribs during using two or five pieces of discrete ribs per pitch.

Taslim et al. [6] and Ekkad and Han [7] used the liquid crystal approach, the researchers assessed the local distribution in a duct with distinct ribs. Other observations on other experimental settings, such as a very narrow duct with two-piece distinct ribs, are also fascinating by Chyu and Natarajan [8] Hu and Shen [9] wrote a converging route with seven-piece-discrete ribs. According to the findings of prior research, appropriately organized discrete ribs induce more heat transmission on the duct wall than continuous ribs, as demonstrated by Khudheyer and Sarah [10] indicated that intermittent ribs have the largest overall performancefactor, However, among the examples analyzed, continuous ribs have the lowest overall performance factor, intermittent ribs have the greatest friction factor values, and the case of intermittent-continuous-intermittent ribs is followed by the continuous rib case. Han and Zhang [11] hypothesized that fractured or distinct ribs may produce more secondary flow cells and local turbulence than continuous ribs, and hence perform better. Han et al. [12, 13] examined the influence of rib inclination angle (α) and rib pitch-to-height (p/e) on heat transfer coefficient and pressure drop in a rectangular duct with rib attachment on two opposing side walls.

In comparison to the other cases of rib arrangement, they discovered that when the pitch ratio was 10 and a rib inclined angle is 60°, the higher heat transfer distribution and friction factor occurs. One of the earliest investigations on the heat transfer distribution and friction factor for 90° and 45° V-shaped ribs with a fixed pitch-to-height ratio p/e=10 in a square channel was undertaken by Taslim et al. [14]. They stated that 45° inclined ribs and V-shaped ribs had better heat transmission and friction losses than 90° inclined ribs. In annular flow, White and Wilkie [15] discovered that P/e = 8 at a 33-degree helix angle resulted in the greater the rate of heat transfer per unit of pumping power. Han et al. [16] observed that for P/e =10, the rib with a 45° angle of attack gave greater performance per unit friction expenditure in parallel-plate flow. In circular tube flow, Gee and Webb [17] and Sethumadhavan and Raja Rao [18] found that P/e= 10 to 15 at a rib angle of attack of about 50-60 degrees provided the best outcome. Burggraf [19] provided the first experimental data on turbulence in a square channel with two ribbed walls on opposing sides with α = 90 deg, P/e= 10, and e/D = 0.055. The Nusselt number augmentation on the ribbed side wall and the smooth side wall was 138 and 19 % greater than the four-sided smooth duct flow values, respectively, while the friction factor was around 8.6 times higher.

Cho et al. [20] observed high heat transfers at a 60-degree angle of attack and excellent thermal performance at a 45-degree angle of attack. Furthermore, Rau et al. [21] investigated the impacts of secondary flow on heat transfer and pressure drop characteristics in a stationary duct using numerous factors such as rib height (e), rib angle of attack (a), rib shape, rib arrangement, and discrete ribs. Kim et al. [22, 23] employed the general response surface approach with dimensionless design factors to optimize the geometry of the ribbed channels in previous investigations. They concluded that this strategy was effective in determining the ideal rib geometry for improving heat transfer. However, they used the general method to achieve an ideal shape for rib-to-rib pitches greater than 10, which has disadvantages such as narrow design variable ranges and low physical reaction. Because of these constraints, the optimum findings obtained differed from earlier experimental results given by several researchers. Sarah and Khudheyer [24] found that the intermittent ribs case has the best thermal performance and the highest friction factor values, while the continuous rib case (CR) has the lowest friction factor values.

The strength and extent of the recirculation zones behind the step are increased when the contraction ratio is increased, according to Mushatet [25]. (i. e. with the in-crease of a step height). With increasing the contraction ratio, the length of reattachment and the size of recirculation zones after the ribs decreased. The change of turbulent kinetic energy and Nusselt number is also influenced by the contraction ratio and Reynolds number. Hakan et al. [26] demonstrate that when the aspect ratio of the obstruction grows, the rate of heat transfer is boosted, and that this tendency is influenced by step height. The findings also showed that when the obstruction aspect ratio rises, the pressure drop reduces. The present study tests heat transfer enhancement in a solar air collector integrated with rib turbulators. The ribs are placed on the absorber plate which is heated by solar irradiance varied from (330 to 850) W/m^2 using solar Simulation System. The solar air collector includes three cases of roughened absorber plate as a smooth plate, a plate roughened with eight transverse ribs (TR 90°) and a plate roughened with six inclined ribs (IR) at three angles of attack (30, 45, and 60 degrees) for a constant air mass flow rate of 0.022 kg/s.

EXPERIMENTATION

An experimental set-up been designed for a solar air collector integrated with different absorbing roughened plates was shown in figure (1). The key pieces in table (1) are incorporated into the main construction of the solar simulator test system. The schematic diagram of the experimental set-up is display in figure (1).

Table 1. The experimental parts of the collector

1	Iron Frame	8	Variac
2	Radial Fan	9	Multi Meter
3	Halogen Lamps	10	Thermocouples Hole
4	Solar Power Meter	11	Outlet Duct
5	Temperature Data Logger	12	Inlet Duct
6	Pressure Digital Manometer	13	Glass Cover
7	Pressure Gauge Hole	14	Anemometer

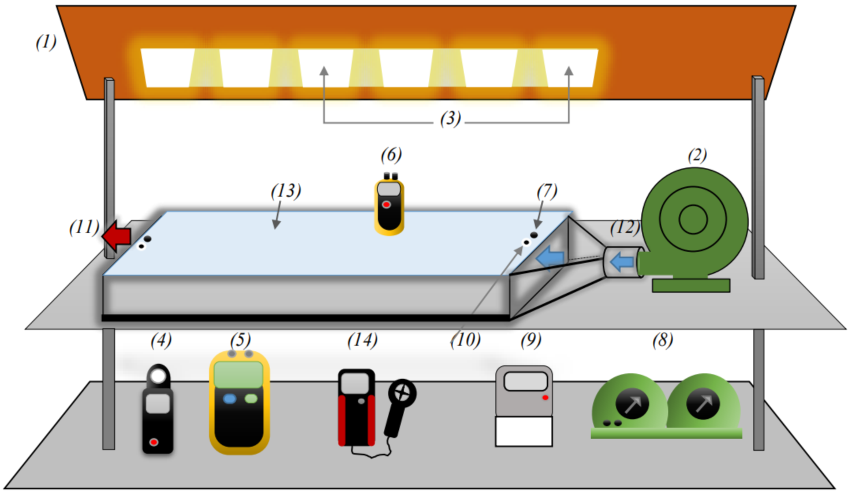

Figure 1. Schematic diagram of the test rig.

As shown in figure (2), the main parts of the solar include collector are solar air duct of dimensions (1250 mm, 360 mm, 50 mm) with absorbing plate of different roughness, the halogen lamps and a glass cover. Six halogen lamps of (500W/ m^2) were used to get the required heat source for the absorber plate. The solar air collector was positioned at an angle proportional to Nasiriya city (31.054°) during the test. The best reading of solar irradiance intensity was determined at a distance of 15cm between the glass cover and the halogen lamps.

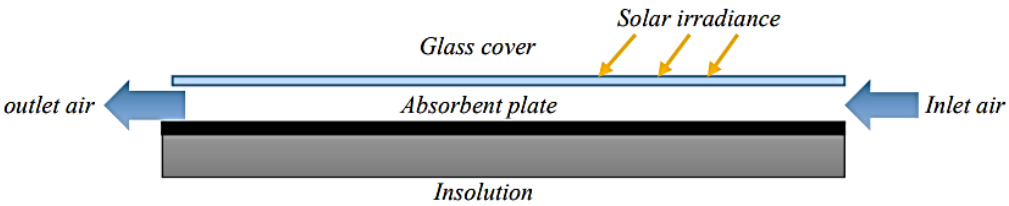

Figure 2. Schematic view of single-pass solar air collector

The current research focuses on angling the ribs transversely at various angles (90°, 60°, 45°, and 30°). The dimensions of rectangular ribs are 350mm, 20mm and 30mm. It's painted with black thermal dye. rib height-to-duct height ratio (e/H) 0.6, with pitch ratio of (p/e) 10, as shown in figure (3). The experiments were performed for different hourly solar irradiance.

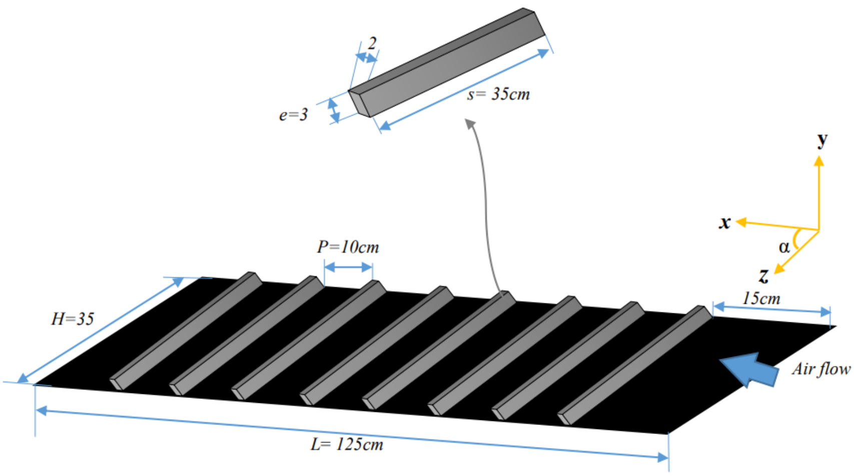

Figure 3. Schematic view of arrangement ribs.

Experimental data reduction

In this experiment, different studied parameter such as wall temperature, inlet and outlet airflow temperature, thermal efficiency and useful energy were conducted as:

The mass airflow rate value is gained by:

$$\dot{m} = \rho a . Vm . Ac \quad (1)$$

The thermal efficiency of the collector is calculated as:

$$\eta = Qu/I . Asur \quad (2)$$

The surface area of the absorber plate can be obtained by:

$$Asur = L . W \quad (3)$$

The useful thermal energy is calculated as:

$$Qu = \dot{m}\ Cp\ (Tout - Tin) \quad (4)$$

The mean heat transfer coefficient ($\bar{h}$) is calculated by the following expression:

$$\bar{h} = Qu / Asur . (Tp - Tb) \quad (5)$$

Where the absorber plate temperature is attained by:

$$Tp = 1/n\ (\Sigma Tpi) \quad (6)$$

The following attain the mean bulk temperature:

$$Tb = (Tout + Tin)/2 \quad (7)$$

The Nusselt number (Nu) is estimated as follows:

$$Nu = \bar{h} Dh / k \quad (8)$$

The hydraulic diameter is gained by:

$$Dh = 4Ac/p \quad (9)$$

$$Ac = W . H \quad (10)$$

$$p = 2(W + H) \quad (11)$$

RESULTS AND DISCUSSION

In a turbulent flow regime, the findings are obtained for parallel ribs in a solar air duct. Two rib configurations (TR and IR) are selected with a pitch ratio (p/e) of 10, a height-to-duct height ratio (e/H) of 0.6, a constant mass flow rate of 0.022 kg/s, and solar irradiation ranging from (330 to 850) W/m^2. The effect angles of attack and solar irradiance on outlet air temperature are depicted in figure (4). It is noticed that the temperature rises when the intensity of the solar radiation increases where, it reaches a maximum value at 1PM (semi linear variation). It was found that the arrangement of the transverse ribs (TR) on the absorbing surface gives a higher temperature than the smooth surface by about 20%, that is because recirculation flows are created. In addition, the hot outlet air temperature for the rib with an angle of attack (α =30°,45°, and 60°) was improved up to about 8%,14%, and 17% respectively, higher than the rib with a 90°. This due to more created secondary flow and destroy of thermal boundary layer with the decrease of angle of attack.

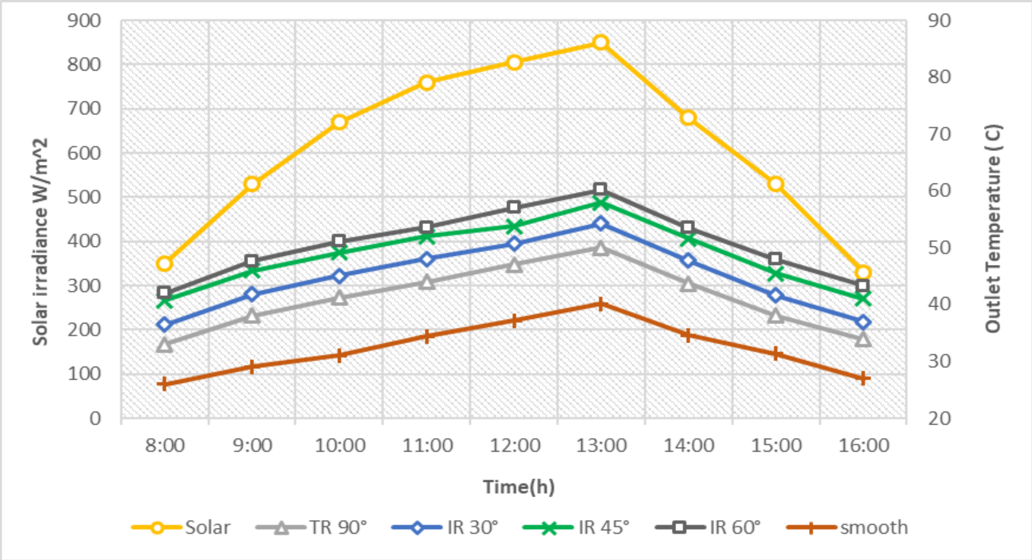

Figure 4. Solar irradiance and outlet air temperature versus different time (h) for the considered cases.

Figure 5, show the variation of Nusselt number in the presence of the effect of solar radiation for different angles of attack. The statistics demonstrate that when solar irradiance increases, the Nusselt number increases, whereas the mass flow rate remains constant at 0.022 kg/s. The Nusselt number at the ribs with α = 90° is greater than that of the smooth plate by about 2.9 times. The Nusselt number with α = 30°, 45°, and 60° is around 3%, 6%, and 9% greater than the Nusselt number with α = 90° at 1 PM. The ribs having an oblique angle (IR) to the flow appear to have a greater influence compared to the transversal ribs (TR) due to the complicated secondary flow field formed by the inclined angle of ribs.

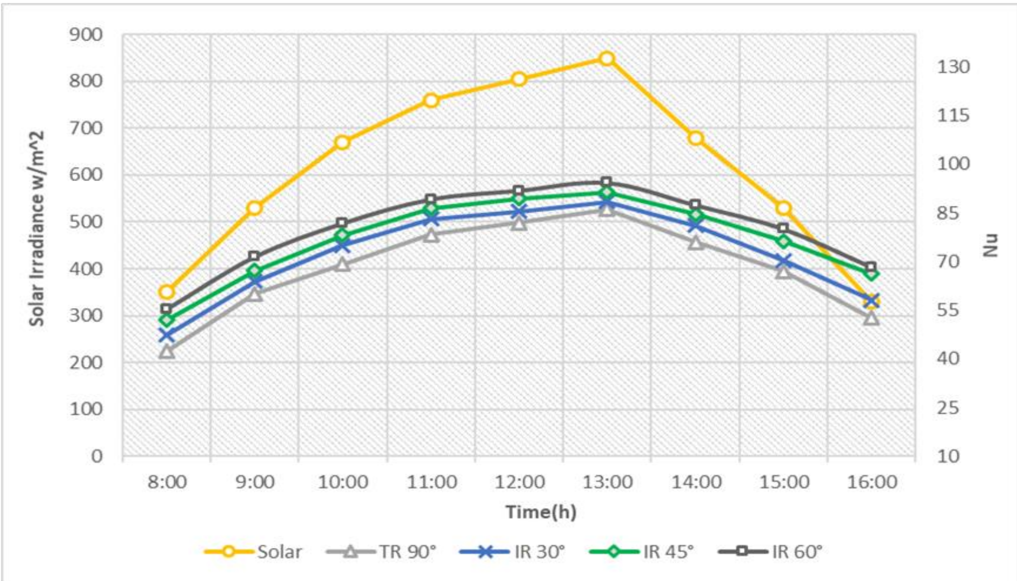

Figure 5. The variation of solar irradiance and Nusselt number with time (h) for the considered cases.

Figure (6) illustrates the effect of angle of attack on the variation of useful energy for different hourly solar irradiance at January. The useful energy is significantly increased with the increase of solar radiation intensity and the decrease in angle of attack (semi linear variation). The maximum values are found in IR 60° as compared with the other cases and smooth plate because the maximum values of the outlet air temperature are found and the temperature difference is increasing, consequently the useful energy (Qu) is increased. The effect of solar radiation intensity and ribs angle of attack on the temperatures difference (T_o - T_i) is demonstrated in figure (7). As the figure shows, the values of the temperatures difference are increased with the decrease of ribs angle (α), because the outlet temperature is increased as the angle of inclination decreases.

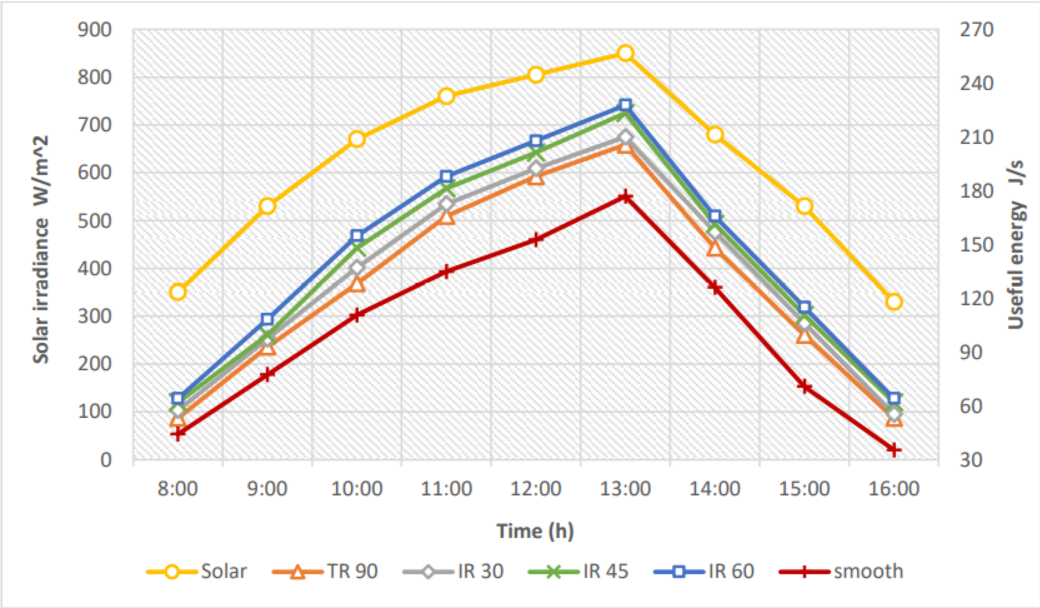

Figure 6. Useful energy and solar irradiance versus time (h) for the considered cases.

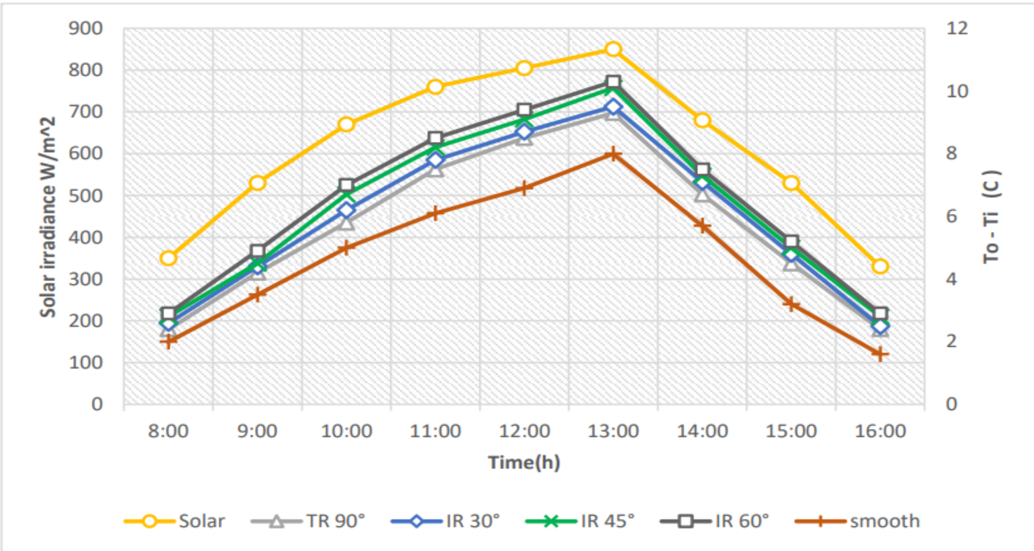

Figure 7. Temperatures difference versus time (h) for the considered cases

Figure (8) demonstrates the variation of thermal efficiency with time for different values of angles of attack of the ribs and solar radiation. The experimental results of these tests showed an improvement in thermal efficiency as compared to the smooth duct, especially at the case of IR 60 that showed the highest efficiency among the tested cases. It has improved up to about 22 % than smooth surface. While the angles of 60°, 45°and 30° inclined ribs improved significantly about 9.7 %, 7.7 % and 2.3 % respectively, compared with the angle of a 90° in maximum radiation. Methods that improve heat transfer can be explained, as the rib beaters that obstruct the passage of the inlet air and create secondary flows that in turn help the hot air sew with cold air more quickly. The absorber plate temperature for (TR), (IR) and smooth solar air duct versus time and average solar irradiance are depicted in figure (9). It is found the absorber plate temperature decreases with inclined ribs. There was a significant difference in (T_p), when comparing the instances of (TR) and (IR) with smooth solar air heaters. The obtained results reported that the decrease in the values of (T_p) for (IR 60°) was 12 % as compared to the smooth solar air heater at 1 PM. This decrease (T_p) in (IR) turbulators is due to increase the absorption of thermal energy and the mixing and recirculating hence the air so it gives better enhanced of heat transfer.

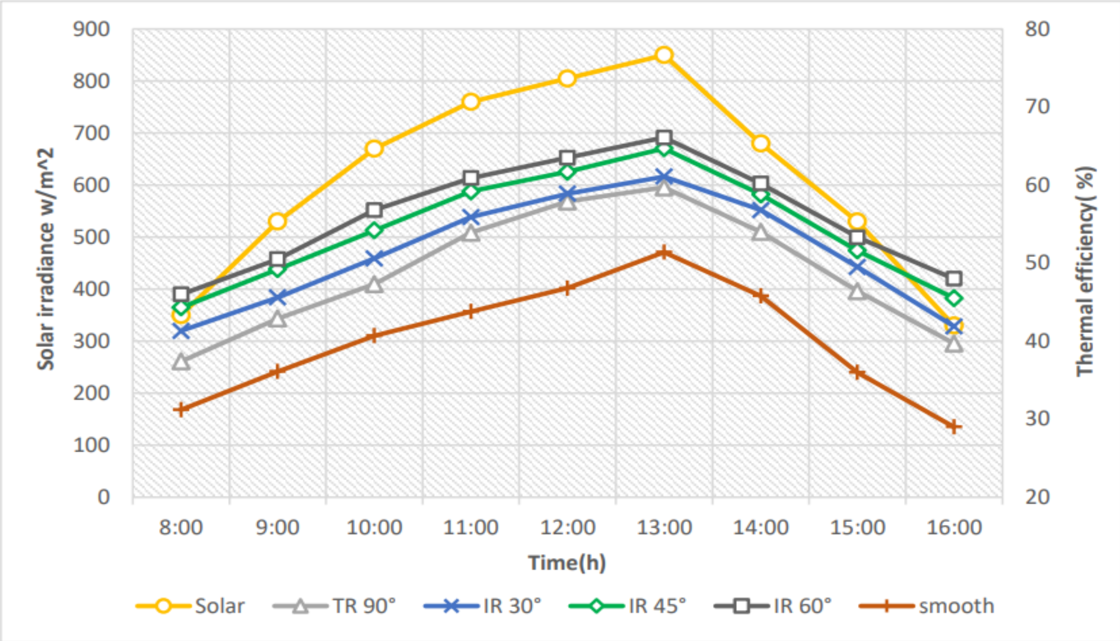

Figure 8. Variability in thermal efficiency (%) with time (h) for the considered cases.

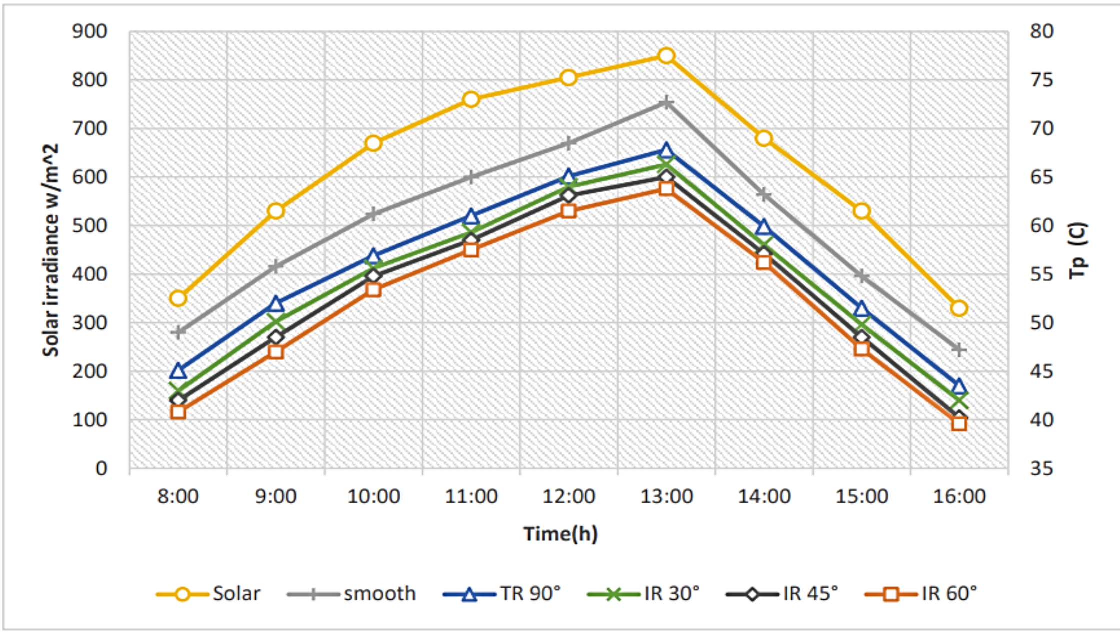

Figure 9. Absorber plate temperatures and solar irradiance versus time (h) for the considered cases.

Figures (10) show a comparison between the present results and published results of Han et al. [27] and Kim [28]. They conducted a thorough investigation to determine the Nusselt number for the duct with TR and IR arranged with e/Dh = 0.063 for (Han) and e/Dh = 0.055 for (Kim) at MFR = 0.022kg/s and (p/e) = 10. A 90°, 60°, 45° and 30° of angles of attack are selected to test. It can be observed that the relative deviations between the results not exceed 10.7% for Nusselt number (Nu / Nu_O) results. This deviation is due to a difference in the value of the duct configuration.

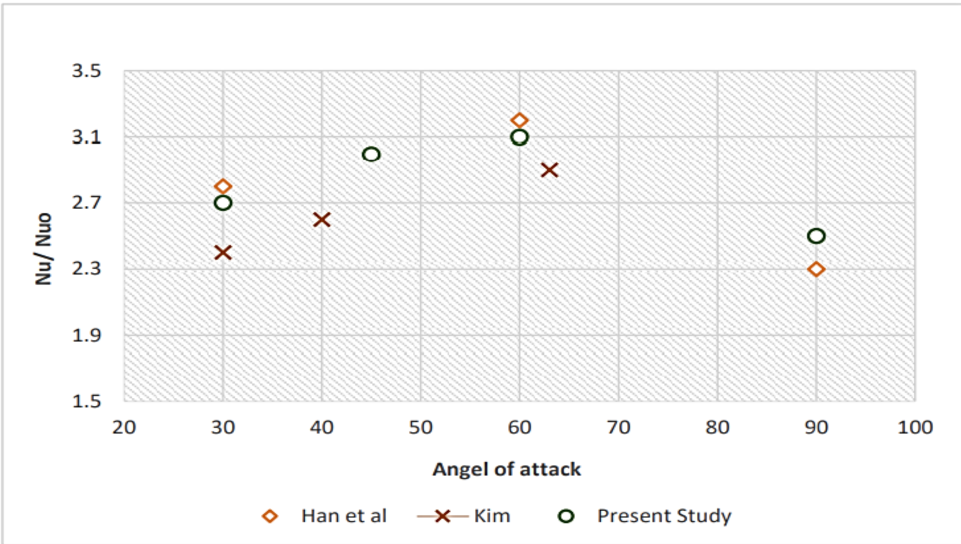

Figure 10. Comparison between the present results and published results.

CONCLUSIONS

Heat transfer enhancement in a solar air duct roughened with various orientation of ribs was examined experimentally for different values of solar irradiance at MFR =0.022 kg/s. The following are the major conclusions:

- Outlet air temperature significantly increases with the presence of Inclined ribs as compared with the values that gained from smooth surface.
- Nusselt number has the highest values in IR 60° case compared to the other cases, it is reached 63%.
- The duct with Inclined ribs 60° indicates the maximum value of the thermal efficiency (η = 66.1%) at maximum irradiance, I=850 W/m^2.
- The useful energy of the oblique ribs (IR) has higher values than the transverse ribs (TR).

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