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Vacuum Effect on the Performance of Solar Air Collector with Micro-Channel Absorber Plate

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Abstract- *In this study, the effect of vacuum with micro-channel technique on solar air collector performance is investigated experimentally. Vacuum space reduces the loss of heat for the absorption plate by conduction and thus improves the solar collector performance. It has been demonstrated that the solar collector is evacuated to 0.1 bar of pressure for absorber-to-cover spacing of 4cm. An absorber plate was manufactured from Aluminum metal with 30 rectangular micro-channels (length 0.9, width 0.004, height 0.0008 m) is constructed with measurements facilities of velocity, temperature and differential pressure. The tests are carried out indoor using solar simulator. Results showed that the performance of solar collector increases with vacuum about 2-5% than gained with non-vacuum utilizing a micro-channel absorber plate-black surface.*

Keywords- *Micro-channel, Solar collector, Vacuum.*

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1. Introduction

Solar energy has a large possibility for applications that have low temperature, mainly for agricultural products drying. Solar energy is an ideal option for drying and heating space, due to use warm air directly, eliminating the need for an additional heat exchanger in the thermal system. A flat-plate solar air collector comprises basically of an insulated housing fitted that supports the metallic absorbent plate and covers of one or more glass or plastic.

In order to raises the operating temperatures and collection efficiencies of flat plate solar collectors, moderate vacuum environments were used by Eaton and Blum 1975 [1]. The operation of vacuum solar collectors that connected to a warm water storage has been presented by Georgiev 2005 [2]. Also using differential equations that describe the solar collectors and the storage, simulation of the installation has been performed. Flat vacuum glazing was manufactured a narrow space evacuated between two glass panels separated by a set of small support columns by Fang et al. 2006 [3]. With the help of a mathematical model, thermal and thermohydraulic performance of smooth as well as roughened solar air collector has been investigated by Bhushan and Singh 2012 [4]. Thermal performance of a new design of minichannel-based solar flat-plate collector has been investigated by Mansour 2013 [5]. The heat transfer enhancement of micro-channel heat sinks with periodic expansion–constriction cross-sections is investigated both experimentally and numerically by Chai et al. 2013 [6]. Computational fluid dynamics (CFD) is an important tool to analysis hydraulic and thermal behavior of microchannel is studied by Desai and Subhedar 2013 [7]. Li et al. 2014 [8] presented the mathematical model for simulating the thermal performance of vacuum glazed transpired collector with slit-like perforations. The absorber plate temperature distribution for compact solar thermal collectors is investigated experimentally and theoretically by Oyinlola et al. 2015 [9]. The convective heat losses resulting in higher efficiencies is reduced by creating a vacuum (less than 0.01mbar) around a solar absorbent due to use evacuated windows. Prototypes of flat vacuum panels with solar applications were fabricated and tested by Arya et al. 2015 [10]. Heat transfer enhancement in microchannel using extended surface has been carried out numerically by Yadav et al. 2016 [11]. The solar radiation conversion into thermal energy of a fluid in flat structures by using a new concept of high-vacuum glazing application has been investigated by Shepovalova et al. 2017 [12]. A methodology for choosing the optimum channel size for a given solar collector plate area in terms of the allowable pumping power and fluid properties has been described by Moss et al. 2017 [13]. An evacuated flat plate thermal collectors Performance has been improved by Moss et al. 2018 [14] by reduce heat losses from a flat panel solar collector by lowering the internal pressure to < 0.5 Pa. The test under the solar simulator, with or without a vacuum, illustrated a sudden drop in heat loss as the pressure dropped to less than 0.5 Pa. Ghahremannezhad and Vafai 2018 [15] provided a comprehensive study using porous substrates in heat sinks of micro-channel to create an improved design that improves the performance of thermal and hydraulic for conventional micro-channels.

In this paper, attention will be focused on the single cover collector and illustrates the utilize of a moderate vacuum environment to reduce heat losses from the absorber by conduction will obtain required temperature and increase efficiency, thus producing a space of vacuum around the absorbent plate and thus taking advantage of properties for the high thermal insulation which have been studied by many researchers. The solar air collector performance was studied with the effect of vacuum throughout an outlet air temperature by using micro-channel technique. The tests are carried out indoor using solar simulator consists of three tungsten halogen lamps. Changing the air flow to four values of 0.0019, 0.0029, 0.0044 and 0.0053 kg/sec with four values to irradiance of 200, 400, 600 and 800 W/m^2. An absorber plate with 30 rectangular micro-channels (length 0.9, width 0.004, height 0.0008 m).

2. Experimental Apparatus

The experimental apparatus is shown photographically and schematically as in Figure 1 and Figure 2, respectively. The experiment consists of the following- :

1) Main Test Section (solar collector).
2) Solar simulator (Tungsten halogen lamps).
3) Centrifugal fan (Blower).
4) Vacuum pump and pressure gauge.
5) Control valve.
6) Voltage regulator.
7) Temperature sensors (Thermocouples).
8) Arduino.
9) Measurement Devices: -

a) Temperature Recorder 12 Channels (Temperature measurement).
b) Digital manometer (Pressure measurement).
c) Vane type thermo-anemometer (Measurement of air velocity).
d) Solar Power Meter (Irradiance measurement).

In the experimental work, two cases are studied; with and without vacuum effect. Firstly, the micro-channels of solar air collector are supplied with fresh air. Temperature sensors (Thermocouples) read the absorber plate and air temperatures. The inserted type thermocouples are installed at the surface of absorber plate at 4 points and 2 sensors in the inlet and outlet air ducts to measure the average temperature of plate and air temperature, as shown in Figure 3. Air get into the solar collector at inlet temperature (Tin) that is supposed to be equal to the room's normal temperature (ambient temperature) and is fixed at 25°C. Solar collector with micro-channels absorber plate as shown in Figure 4. Digital manometer is used to measure the pressure drop across the duct. The solar simulator used in this experiment consists of three-tungsten halogen lamps. The radiation intensity falls on the collector is measured by a solar power meter. The electronic circuit use in current study to meet the thermal requirements for solar collector, in experiments, the temperature using control circuit. The aim of this work is controlling the temperature of air out from solar collector by the blower fan, to find the required velocity for air temperature to stay in allowable limits. The velocity of fan is increase with increasing the temperature of air from starting until it reaches to temperature range at constant power.

3. Mathematical Formulations

The hydraulic diameter is calculated by: -

$$Dh = \frac{4(free\ area)}{wetted\ \ perimeter} = \frac{4 * Wch * Hch}{2(Wch + Hch)}\ . \quad (1)$$

Reynolds number, Re is defined as,

$$\mathrm{Re} = \frac{\rho v d}{\mu} \quad (2)$$

$$m^{\cdot} = \rho v A \quad (3)$$

The useful power of solar air collector can be evaluated using the equation:

$$Q = m^{\cdot} * C_p * (T_{aout} - T_{ain}) \quad (4)$$

The above-mentioned equation will give the fundamental tools in order to clear up and comprehension the importance of the data acquired better as the averaged heat transfer coefficients are defined as

$$h = \frac{Q_u}{A_s * (T_W - T\ \ )} \quad (5)$$

Where As = (2H + 2W) L. The temperature of the channel wall (Tw) is supposed to be uniform and that equal to the average four readings of thermocouples that exist on the upper surface of test section.

$$\text{Where } T\ \ (\text{Average mean temperature}) = \frac{T_{in} + T_{out}}{2} \quad (6)$$

The average number of corresponding Nusselt is defined as follows:

$$N_s = \frac{h * D_h}{K} \quad (7)$$

*Empirical equations that gain from Figure 12 are:

Nu=0.0003Re-0.12 without vacuum at 200 W/m^2

Nu=0.0003Re-0.0148 with vacuum at 200 W/m^2

Nu=0.0003Re+0.1706 without vacuum at 800 W/m^2

Nu=0.0003Re+0.2233 with vacuum at 800 W/m^2 (8)

4. Results and Discussion

The heat transfer from the hot absorber plate to the flowing air is increased by using the micro-channel technique due to its small hydraulic diameter (Dh). This increment in heat transfer is usually accomplished with an additional pressure drop. There are 30 of micro-channels distributed on the base plate that has a dimension (90 cm of length, 15 cm of width and 0.6 cm of height) including 15 channels on the top surface and 15 channels on the bottom surface, and the distance between channels is 5 mm. It includes a standard set of 32 aluminum fins, design of rectangular type fins at 1.3 mm of hydraulic diameter with channel length, channel width and channel height 900mm, 4mm and 0.8 mm, respectively, as shown in Figure 4 .

In the vacuum case, the gap between the absorbent plate and the glass cover offers a high level of thermal insulation around the absorbent plate, which reduces the loss of heat by conduction from the absorbent and thus maximize the performance of solar air collector. The variation of temperature over the length of the absorber plate for air flow (0.0019 kg/s) with and without vacuum is shown in Figure 5. The maximum temperature rise obtained, without vacuum, of the absorber plate is 99.2 °C, whereas, in vacuum case it is obtained 105 °C at airflow of 0.0019 kg/s (minimum air flow) and irradiance of 800 W/m2. Figure 6 illustrates the variation of absorber plate temperature with distance from air entrance for air flow (0.0053 kg/s) with and without vacuum. The variation of glass cover temperature along the solar air collector at different irradiance values with and without vacuum is demonstrated in Figure 7. It was observed that the difference of temperature between them, with and without vacuum, about (3-4.5) °C due to reduce heat loss between the absorber plate and glass cover. The variation of air outlet temperature with irradiance at different values of air flow with and without vacuum is demonstrated in Figure 8. The outlet temperature of the air increases as irradiance increases from 200 to 800 W/m2, and decreases as the air flow increases, the highest outlet air temperature is 74.5 °C, while 70 °C without vacuum. An experimental variance of temperature difference of air ΔT (°C) with air flow at different values of irradiance with and without vacuum is illustrated in Figure 9. Figure 10 demonstrated the experimental variance of temperature difference of air ΔT (°C) with irradiance at different values of airflow with and without vacuum. Figure 11 demonstrates the variation for coefficient of heat transfer (W/m^2 K) with air flow of the solar collector at different values of irradiance. The amounts of Nusselt number with an adapted Reynold number for different irradiance, with and without vacuum, is plotted in Figure 12, the amount of Nusselt number is low due to high collector length. Results showed that the performance of solar collector increases with vacuum about 2-5 % than gained with non-vacuum utilizing a micro-channel absorber plate-black surface.

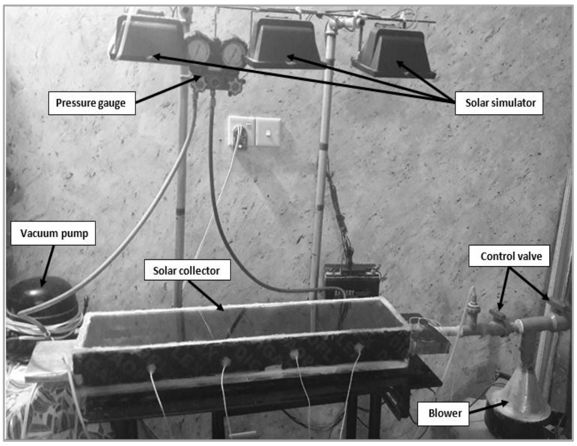

Figure 1: Photograph of the experimental apparatus

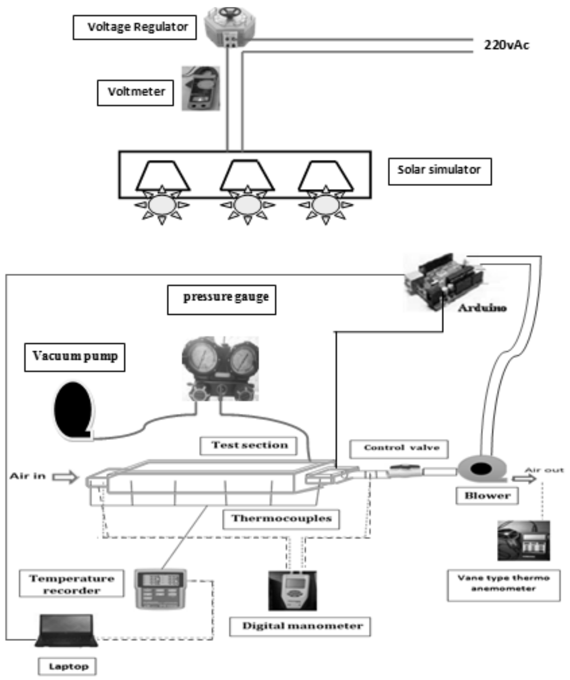

Figure 2: Schematic diagram of the experimental apparatus

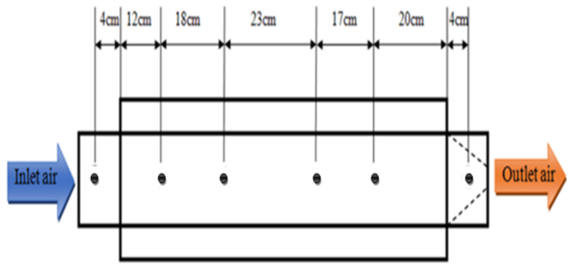

Figure 3: Thermal sensor distribution network on design

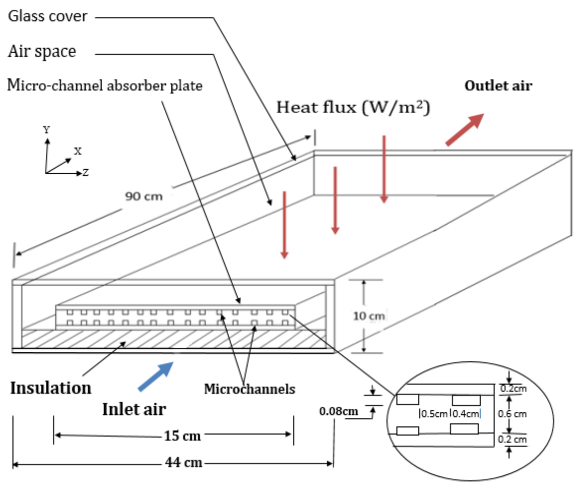

Figure 4: Sketch of solar collector with micro-channels absorber plate

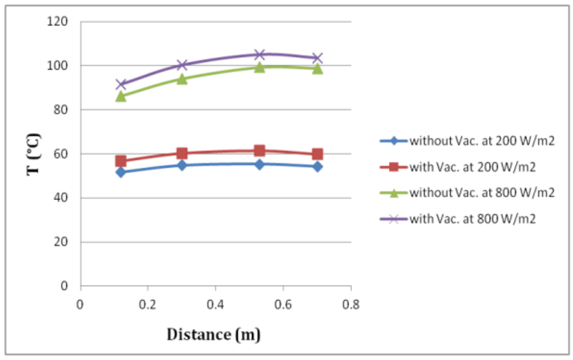

Figure 5: Variation of temperature over the length of absorber plate for air flow (0.0019 kg/s) with and without vacuum

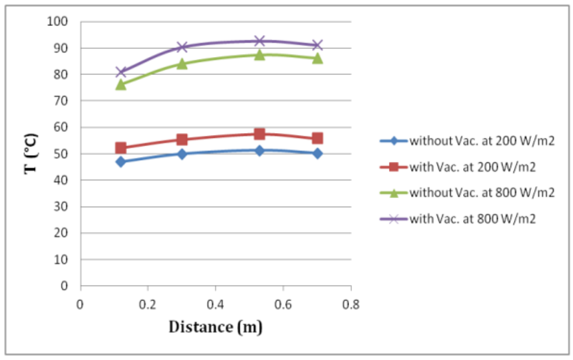

Figure 6: Variation of absorber plate temperature with distance from air entrance for air flow (0.0053 kg/s) with and without vacuum

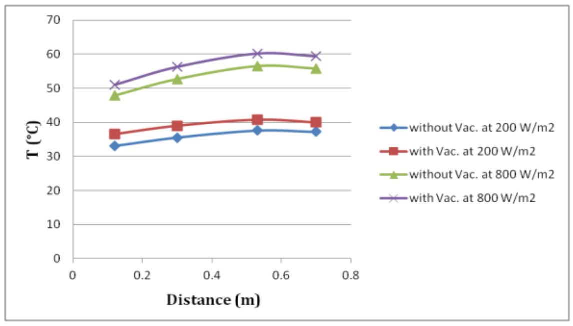

Figure 7: Variation of the temperature of glass cover with distance of the solar air collector at different irradiance values with and without vacuum

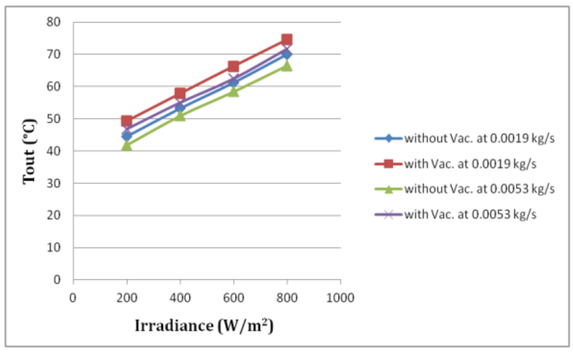

Figure 8: Variation of air outlet temperature with irradiance at different values of air flow with and without vacuum

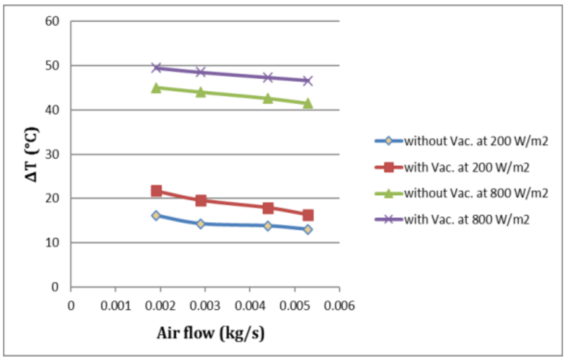

Figure 9: Experimental variance of temperature difference of air ΔT (°C) with air flow at different values of irradiance with and without vacuum

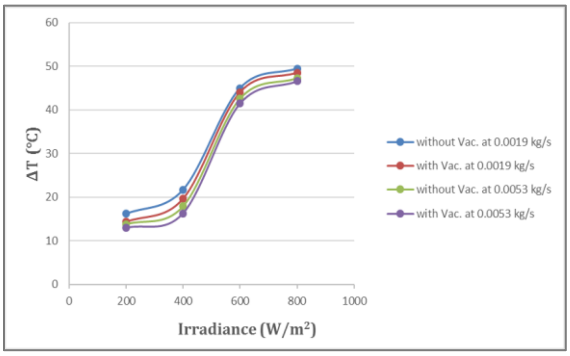

Figure 10: Variance of the temperature air difference with irradiance at various amounts of airflow with and without vacuum

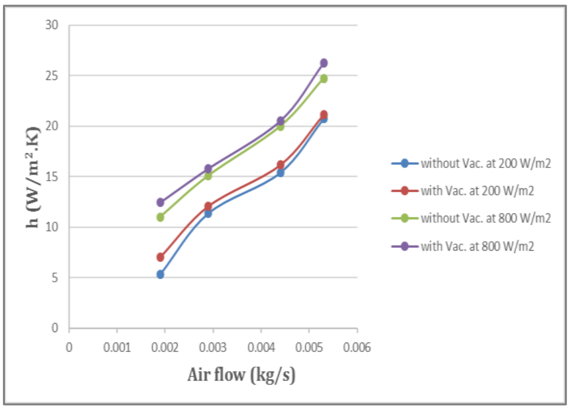

Figure 11: Variation for coefficient of heat transfer (W/m² K) with air flow of the solar collector at different values of irradiance

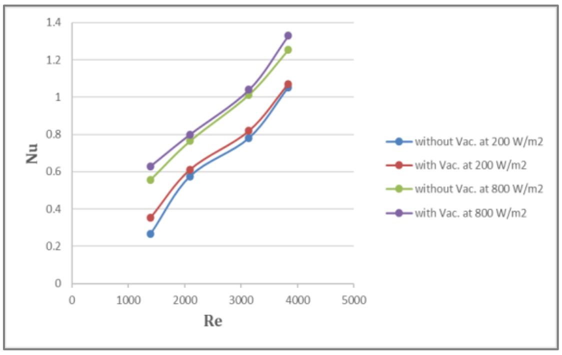

Figure 12: The amounts of Nusselt number with an adapted Reynold number for different irradiance with and without vacuum

5. Conclusions

1. The performance of solar collector has been improved by using vacuum technique that gains the highest air temperature difference (ΔT) between inlet and outlet air temperature is 49.5 °C, whereas 45 °C without vacuum.
2. By using micro-channel technique, the heat transfer has been improved due to its small hydraulic diameter (D_h).
3. The value of heat transfer coefficient was low, reached of 24.7 W/m².K without vacuum whereas 26.2 W/m².K with vacuum, due to the length of collector is high.
4. Electric control is very important to control the temperature of air out from solar collector by the blower fan, to find the required velocity for air temperature to stay in allowable limits.

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