Thermal Analysis of Jet Impingement Solar Air Collector

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Abstract: A jet impingement solar air heater system was fabricated and tested indoor with solar simulator. The inlet and outlet channels of the solar collector was separated by a perforated plate, which allowed the air to pass through the holes and impinged at an absorber flat plat. Three different designs of perforated plates were investigated, which are 6mm of hole diameter with square and triangular geometries, and 10mm of hole diameter with triangular geometry. Rise of temperature was used to evaluate the thermal performance. It is found that temperature decreases with increase of the inlet airflow rate. 6mm of hole diameter gives higher rise of air temperature compared to the 10mm, however, geometry design does not show strong influence in overall thermal performance.

1 Introduction

Malaysia as tropical country receives abundant solar radiation and having an average daily solar radiation of about 500-700W/m² (Sopian and Othman, 1991). This could be used for drying of agricultural products, space heating and air conditioning, industrial processes (textile, paper, etc.) and green house heating using solar air collector devices (Inci Türk Togrul and Dursun Pehlivan, 2003). The solar air collectors occupy an important place among solar heating systems because of availability, minimal cost and the direct use of air as the working substance reduces the number of required system components. However, the primary disadvantage of solar air collectors system is the need for handling relatively large volumes of air as a working fluid with low thermal capacity, poor thermal conductivity and the convective heat-transfer rate inside the air flow-channel where the heated air is low, and a great deal of effort has been made to increase this rate. Many ways have been done to improve the convective heat-transfer rate such as increasing the heat-transfer surface area and increasing the turbulence inside the channel by using fins, corrugated surfaces, obstacles, porous bed materials, and applied the recycle-effect concept in double-pass operations (Wenfeng Gao et al, 2007). However they also can significantly increase the pressure losses within a collector (Belusco et al, 2008). Our hypothesis is that a solar air collector using jet impingement has advantages such as; high convective heat-transfer rate, low pressure losses, low pump power and low cost. The objective of this research is to study the fundamental of heat transfer and fluid flow in a jet impingement solar air heater system by designing, fabricating, testing and evaluating the system performance.

2 Experimental Setup

2.1 Design and Fabrication of the Jet Impingement Solar Air Collector

The test rig of a Jet Impingement Solar Air Collector was put under the solar simulator with varying height and power range. For the experimental work reported here, the Jet Impingement Solar Air Collector was placed at the best position under the solar simulator with the highest and the most uniform intensity to acquire the experiment dataas shown in Figure 1. Several designs of the perforated plate were investigated as shown in Figure 2. They are
aluminum flat plates coated with selective black spray-paint.

Figure 1. Schematic diagram of a jet impingement solar air collector experimental set up

Figure 2. Schematic diagram of an aluminum perforated plates with different plate design: (a) 6mm and triangular, (b) 6mm and square, and (c) 10mm and triangular and with 4 cm distance between each holes.

2.2 Evaluation of System Performance

The jet impingement solar air heaters with different absorber designs were tested in the UKM Solar laboratory using a solar simulator. The solar radiation was measured by using a pyranometer at different points on the glass as in Figure 1. The temperatures were measured by using K-type thermocouples and air velocity for inlet and outlet channels were measured by using hot wire anemometer. All the sensors are connected to a data acquisition system that connected to the computer.

3 Experimental Result

3.1 Analysis result

Jet impingement technology is an effective tool in controlling the fluid flow for high energy transfer, which directs a jet flow from a nozzle of a given configuration to a target surface. Due to the thin thermal and hydrodynamic boundary layers formed on the impingement surface, the heat transfer coefficients associated with jet impingement are large. The convective heat transfer configuration is used for its high local transfer coefficients nearby the stagnation point. The wall impinging jet flows are widely used in engineering applications such as turbomachinery, food processing, drying, cooling and heating (Angioletti, 2003; Joshi, 2003; Na-pompet, 2011; Sagot, 2008).

Some researches on solar air heater have applied this technology to enhance the heat transfer between the air and the absorber. Choudhury and Garg (1991) simulated the thermal performance of solar air heaters with a glazed solar collector where the metallic jet plate was placed in between the absorber and the back plate, whereas Belusko et al. (2008) examined the performance of jet impingement in an unglazed roof. Both studies have found that the jet designs give better thermal efficiency compared to the conventional parallel plate. Choudhury and Garg (1991) proposed a design with configuration that forces the air to flow through the perforated absorber to create jet impingement effect on a flat absorber at the outlet channel as shown in Figure 3. Though in this previous work they simulated that this design is able to give better heat transfer, the solar collector has not been tested experimentally. Thus, the experimental
investigation in this project is to verify the collector performance with different perforated plate designs.

Figure 3.
Configurations of the solar collector with double absorbers

Figure 4 shows the flow direction and the measured temperatures are the mean surface and air temperatures at different points of surfaces and channel respectively.

Figure 4. Flow direction and temperature locations

The experiments results for the three different perforated plate designs of plate are as shown in Figure 5. The experiments were carried out under different ratios of air speed of inlet to outlet.

It is found that all the temperatures decrease with increasing the air speed at the inlet. This indicates that one of the key factors that influence the system temperatures is the inlet air velocity or flow rate. Nonetheless, in terms of temperature change of the system, suction ratio of inlet to outlet of 2 gives better rise of air temperature (Figure 6). Furthermore, among these three designs, two of the 6mm diameter plates give the highest rises of air temperature, which is about 18°C. For the same diameter designs, geometry distribution seem does not play a critical role in overall heating performance. Both square and triangular geometries give about the same results under the same suction speeds. However, 6mm diameter gives higher rise of air temperature compared to the 10mm diameter.
5. Conclusion

A jet impingement solar air heater system was fabricated and tested indoor with solar simulator. The system was tested with three different designs of perforated plates, which are 6mm of hole diameter with square and triangular geometries, and 10mm of hole diameter with triangular geometry distribution. Rise of temperature was used to indicate the thermal performance of this study. It is found that the inlet airflow rate influence the temperatures of the system. 6mm of hole diameter gives higher rise of air temperature compared to the 10mm, however with the same diameter size, geometry design does not show strong influence in overall thermal performance.

References: