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Thermal Performance of Solar Air Heater with Porous Material

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Abstract

This paper presents an experimental thermal performance of flat plate solar air heater with and without porous material. The steel wool was selected as porous materials for this work. The solar radiations was simulated by halogen lights and dimmers and variac were used for regulating intensity. The couple of solar air heaters were constructed for with and without porous material. The experiments were conducted on both of solar air heaters at same location, simultaneously. The experiments were carried out the following conditions: solar radiation of 400, 600 and 800 W/m^2, air mass flow rate of 0.01, 0.015 and 0.02 kg/s and porous material which having porosity of 0.92 and 0.94. The criteria to comparatively study of the thermal efficiency of solar air heater with and without porous material. The experimental results revealed that temperature difference between inlet and outlet of solar air heater increased with increment of solar radiation. Furthermore, the thermal efficiency of solar air heater having porous material was higher than solar air heater without porous material. Thermal efficiency of solar air heater was increased with air mass flow rate increased. In addition, the thermal efficiency will be enhanced because of increasing of heat transfer area due to porous material.

Keywords : Solar Air Heater, Thermal Efficiency, Porous Material, Experimental

I. Introduction

Present, energy demand is increasing continuously which it cause of insufficient energy resource. Therefore, energy is very important and necessary to use efficiently. Most of people in Thailand are work in agriculture and the agricultural products after harvesting have to reduce moisture for storing to keep quality and reducing loss before trading. However, Thailand is located in hot and humid climate which it cause of agriculture product is absorped moisture and affect to quality. Therefore, process to reduce moisture is need to add heat into the air to control temperature and relative humidity. Moreover, Thailand is located close to equator so solar energy has potential to be used in Thailand. Anyway, the method to use of solar energy for agriculture is transformative to thermal energy. Solar air heaters are a kind of heat exchangers that transform solar energy into heat. Since past, every countries have tried to use solar energy to produce thermal energy due to solar energy is not produce pollution and expense. Solar collector or solar air heater is extensively used to transform solar energy to thermal energy. The thermal energy will be applied for other processing (Sreekumar, 2010 and Amer, B.M.A. et al., 2010) such as drying of food and cereal grain, production of hot water, enhancement of heat in building, applied for industrial processes and etc. The components of solar air heater consist of body, transparent material and heat absorber. In the past, many of researchers studied for improving efficiency of solar air heater by means of reduction of heat loss and increasing of heat transfer coefficient between fluid and solar absorber (Akpinar, E.K., 2010 and Moummi, N.A., 2004) such as increase of number of pass for the air, increasing number of fins or, however, put articles obstruct the air flow and etc. Another technique to increase heat transfer coefficient is using porous material which it characterize of high ratio of surface area to volume. Moreover, the porous material assist to enhance capability of thermal energy transformation between convection and radiation which it result in higher heat transfer rate. Due to the mentioned prominent characteristics of the porous materials, more researchers have interested to study of using porous materials for improving solar collector efficiency. The previous study proposed a way to reduce the heat loss from the covered glass on top of the solar collector by replacing of absorber plate with porous material. The result shown that the thermal efficiency of solar collector was increased more than 75% (Mohamad A., 1997). The second researcher studied and tested performance of solar collector with the matrix absorber surface and found that thermal efficiency was increased when mass flow rate increased (Kolb et al., 1999). Another researcher studied thermal efficiency of air recirculation solar air heater with and without porous material, steel wool. The result shown that thermal efficiency of solar air heater with steel wool was increased more than 80% when smallest of gap of steel wool at air mass flow rate was more than 0.05 kg/s. Furthermore, thermal efficiency of solar air heater with porous material was higher than solar air heater without porous material about 20-70% (Sopain et al., 1999). Another research was studied on thermal efficiency and pressure drop of solar air heater with and without porous material. The porous material for this research was glass wool which it was porosity of 0.80. The result shown that thermal efficiency of recirculated solar air heater was higher than without recirculation at about 10-12% and the efficiency of solar air heater with porous material was higher than solar air heater without porous material (Yousef et al., 2008). Moreover, another research was studied and test of thermal efficiency of solar air heater with and without absorbent material. It was conducted by absorbent material in 4 types such as sand, pebble, sand mix with steel and pebble mix with steel. The result shown that thermal efficiency of solar air heater with absorbent was higher than solar air heater without absorbent(Saravanakumaret al., 2010). El-Sebaii et al., (2007) used two different configurations, limestone and gravel as packed bed materials, and obtained 65% thermal efficiency at 0.05 kg/s mass flow rate. Ramani B.M., et al, (2010) studied for performance of double pass solar air collector with and without porous material. The porous material was black painted wire mesh. That result shown that performance of solar air collector with porous material should be increased about 25% for double pass and 35% for single pass. Alvarez G. et al., (2004) proposed to use of recyclable aluminum cans as an absorber plate. The result found that maximum efficiency of solar air heater was increased at 74%. Zheng W. et al., (2017) proposed that the using of metal corrugated packing for solar air collector. The result found that it was more appropriate to be used in rural building of cold region which it advantaged of large heat transfer area, high heat transfer coefficient and good economic performance. The costs of the collector gain more importance, and the need of less expensive collectors is evident. Based on this idea, a rudimentary design of an air solar collector using convenient recyclable material for the absorber plate was built. As of mentioned researches, the porous material has potential to increase the thermal efficiency of solar air heater and suitable for cost reduction of solar air heater. Therefore, the objective of this research to study of thermal efficiency of solar air heater with and without porous material.

Experimental investigation

The indoor test facility to evaluate solar air heater was designed. The solar air heaters were constructed for investigate the thermal performance of solar air heater with and without porous materials. The detail of the experimental setup and methodology are as follow;

Experimental setup

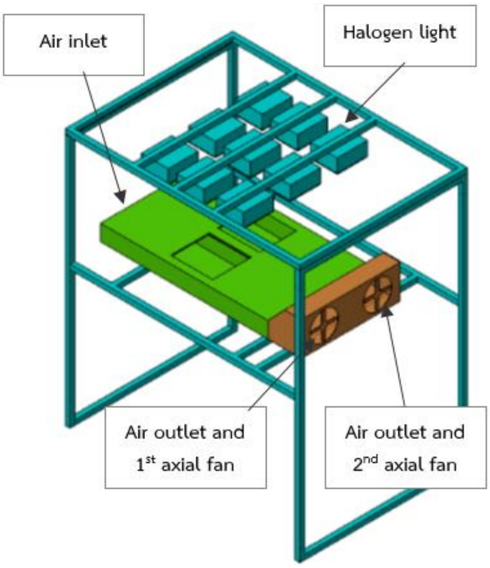

Fig. 1. Schematic diagram of experimental set up

The scheme of the experimental setup is illustrated in Fig.1. The experiment was conducted on a couple of solar air heaters. Dimension of each of solar air heater units were 1 meter in long and 0.3 meter width. The body of both solar air heater was construct by aluminum, painted with black color. All sides and bottom of the solar air heater were insulated with 50 millimeter thick polyurethane foam. The covered glass of 3 millimeter thickness was used for glazing. Single cover glass was used in both of solar air heaters. The axial fan for each solar air heater units was equipped in opposite of air inlet. Solar radiation was simulated by providing halogen lights and settled on a stand in such a manner that irradiation directly falls on the glass cover and get transmitted to the absorber plate. To regulate the solar intensity that solar air heater had received, dimmers and variac were used. The intensity of radiation that the solar air heater was received would be deliberated by digital pyranometer. The flow rate of air through solar air heater was measured by hot wire anemometer. Temperatures of ambient, inlet and outlet air were recorded by data logger with thermocouple type K.

Experimental methodology

The Experiments were conducted into 2 cases, with porous material and without porous material. The porous material was positioned on absorber plate directly and disperse throughout surface of the solar air heater. The experimental setup runs for selected range of parameters for different air flow rate at 0.01, 0.015 and 0.02 kg/s and different solar intensity at 400, 600 and 800 W/m^2. In addition, the differential porosity of porous material at 0.92 and 0.93 were used. The data of the temperature of air at inlet, outlet and ambient have been recorded every 1 minute to calculate the desired output.

Investigation of porosity

Type of porous material is effect to efficiency of solar air heater. Moreover, the material that was easily to discover in the area is important to select. Hence, the selected porous material in this research was steel wool. Usually, method to investigate of porosity could be conducted into 2 methods. First is water substitution and second is calculation from shape of porous material. The methodology of water substitution was done by put steel wool into container which knowing volume until full. After that, fill with water into container and wait for 5 minute, water was infiltrate into porosities of materials, then drained water out. There from, fill with water which knowing volume until full of container and record the water volume, simultaneously. The volume of water was void-space volume, V_s, and volume of container was total or bulk volume, V_T. The porosity, ε, of porous material, steel wool, can be calculated by (1).

$$Porosity\ (\varepsilon) = \frac{V_s}{V_T} \tag{1}$$

The methodology of calculation from shape of porous material was conducted by calculating volume of porous material, V_ε, which having uncomplicated shape and definite shape. Hence, the whole volume of porous material, Vε, has to be examined. The porosity of porous material could be calculated by (2).

$$Porosity\ (\varepsilon) = \frac{V_T - V_\varepsilon}{V_T} \tag{2}$$

Due to shape of porous material in this research was complicated. Therefore, the method to investigate of porosity would be examined by the method of water substitution.

Thermal efficiency analysis

The analysis of efficiency was calculated by the proportion of useful energy per energy input from radiation on considered period. The analysis of solar air heater efficiency was considered on steady state by using equation of Hottel-Whiller-Bliss for calculating of useful energy. The efficiency of solar air heater could be calculated by (3), (4), (5) and (6), respectively. (Duffie A.J. et al, 1991)

$$q_u = \dot{m}C_p(T_o - T_i) \tag{3}$$

$$q_u = F_R(\tau\alpha)A_cI - F_RU_LA_c(T_i - T_a) \tag{4}$$

$$\eta = \frac{q_u}{A_cI} = \frac{\dot{m}C_p(T_o - T_i)}{A_cI} \tag{5}$$

$$\eta = \frac{q_u}{A_cI} = F_R(\tau\alpha) - F_RU_L\frac{(T_i - T_a)}{I} \tag{6}$$

II. Result and Discussions

The results of this research were displayed in term of different air temperature at inlet and outlet of solar air heater and thermal efficiency of solar air heater which it could be categorized in each matters as follows;

Different of air temperature at inlet and outlet of solar air heater

Fig. 2, 3 and 4 show different of air temperature at inlet and outlet of solar air heater at mass flow rate of 0.01, 0.015 and 0.02 kg/s, respectively. The result shown that different air temperature of solar air heater with porous material higher than different air temperature of solar air heater without porous material and, moreover, different air temperature of solar heater with porous material at porosity of 0.92 would be higher than different air temperature of solar air heater with porous material at porosity of 0.94 throughout of every intensities of solar radiation and air mass flow rates.

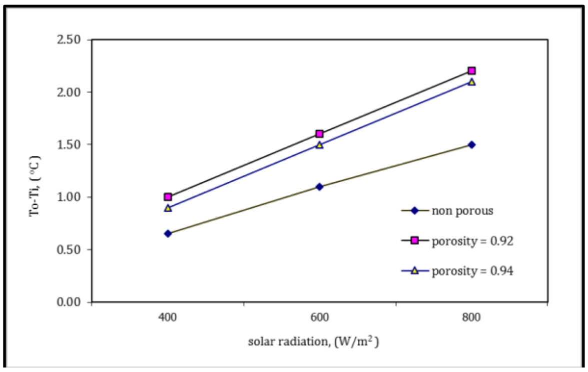

Fig. 2. Different air temperature at inlet and outlet solar air heater at mass flow rate of 0.01 kg/s

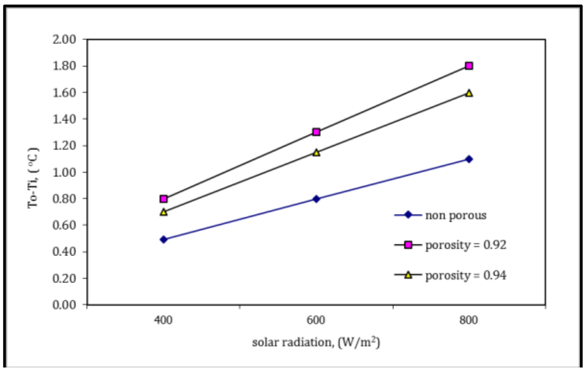

Fig. 3. Different air temperature at inlet and outlet solar air heater at mass flow rate of 0.015 kg/s

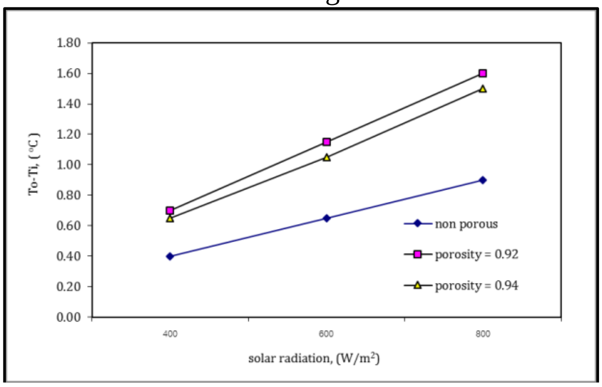

Fig. 4. Different air temperature at inlet and outlet solar air heater at mass flow rate of 0.02 kg/s

Due to porous material absorbed energy from solar radiation and increasing of heat transfer area of the air, moreover, it enhanced heat transfer coefficient. As of result found that different air temperature of solar air heater with porous material would be higher than different air temperature of solar air heater without porous material about 0.6 - 0.8°C. The different air temperature would be increased when the porosity of porous material was lower as shown as porosity of 0.92. The different air temperature solar air heater with porous material at porosity of 0.92 would be higher than different air temperature solar air heater with porous material at porosity of 0.94 at about 0.3°C. Because of porous material which having low porosity would be higher surface area than porous material that having high porosity. Therefore, heat transfer coefficient of solar air heater with low porosity would be increased by increasing of heat transfer area and Reynolds number.

Evaluation of Thermal efficiency

Fig. 4 to 6 show the comparison of (Ti –Ta)/I with thermal efficiency of solar air heater without porous material and with porous materialat porosity of 0.92 and 0.94, respectively. The results shown that thermal efficiencyof solar air heater would be increased when air mass flow rate increased. Moreover, thermal efficiency of solar air heaterwith porous material in every porosities were increased when air mass flow rate increased in whole cases. Because of the Reynolds number would be increased when air mass flow rate increased and result in thermal efficiency enlargement.

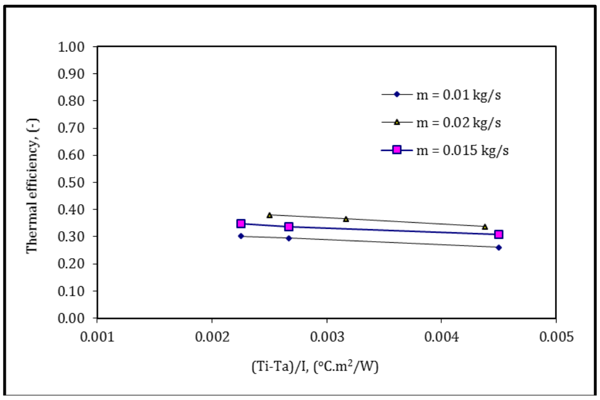

Fig. 4. Thermal efficiency of solar air heater without porous material

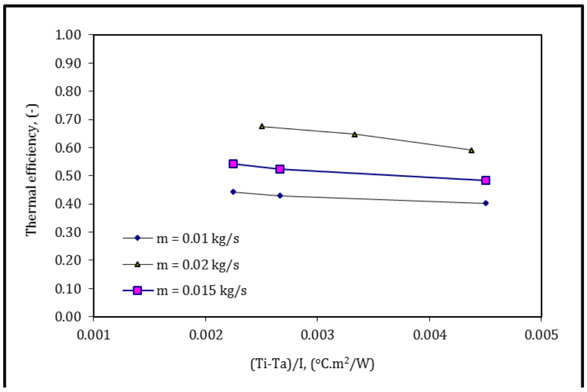

Fig. 5. Thermal efficiency of solar air heater with porosity of porous material at 0.92

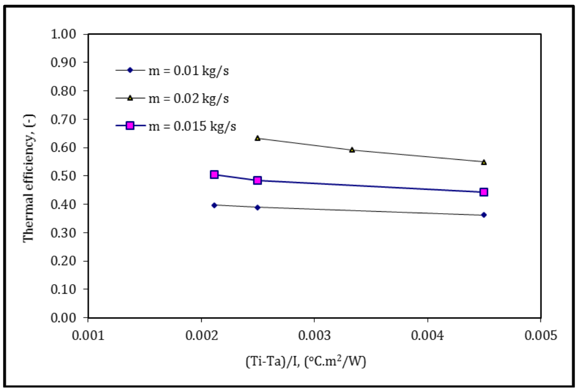

Fig. 6. Thermal efficiency of solar air heater with porosity of porous material at 0.94

Moreover, the thermal efficiency would be decreased when the value of (Ti – Ta)/I increased. Due to heat loss would be higher when the different of inlet air temperature and ambient temperature, (Ti – Ta), increased.

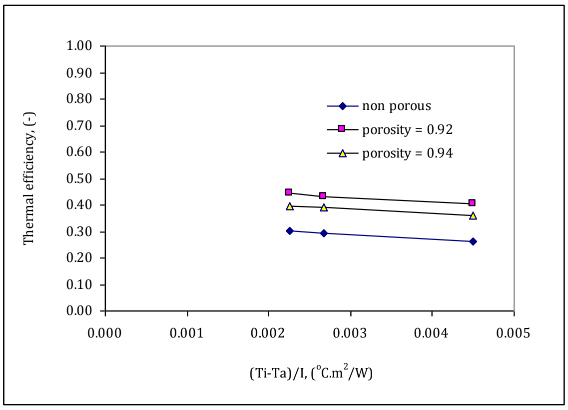

Fig. 7. Thermal efficiency at air flow rate of 0.01 kg/s

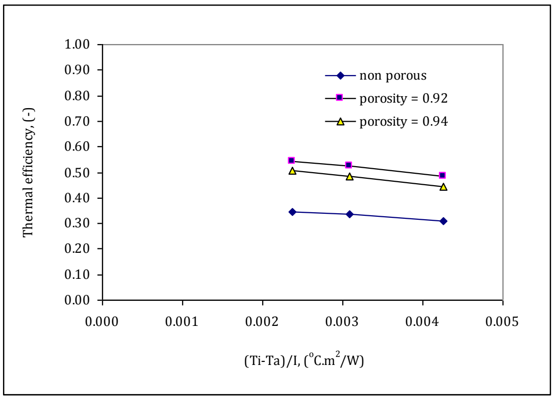

Fig. 8. Thermal efficiency at air flow rate of 0.015 kg/s

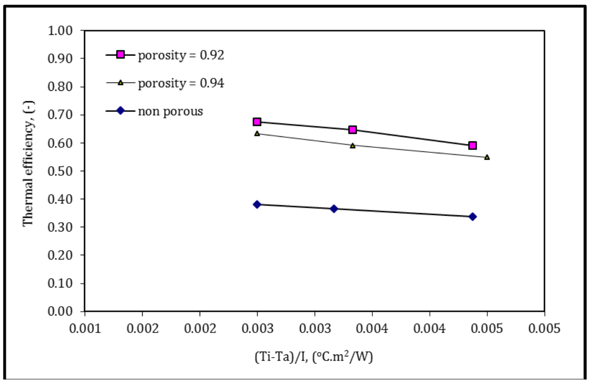

Fig. 9. Thermal efficiency at air flow rate of 0.02 kg/s

Fig. 7, 8 and 9 show the comparison of thermal efficiency of solar air heater without porous material and with porous material at porosity of 0.92 and 0.94 at air mass flow rate of 0.01, 0.015 and 0.02 kg/s, respectively. The results show that thermal efficiency of solar air heater would be enlarged when it used of porous material.Moreover, thermal efficiency would be higher when lower of porosity, while higher of air mass flow rate. Consider at air mass flow rate of 0.02 kg/s to rewrite the relation of results and develop equation form as if (6) as follow;

$$\eta_{non\,porous} = 0.44 - 22.63\frac{(T_i - T_a)}{I}, \ R^2=0.99 \quad (7)$$

$$\eta_{\varepsilon=0.94} = 0.73 - 41.86\frac{(T_i - T_a)}{I}, \ R^2=0.99 \quad (8)$$

$$\eta_{\varepsilon=0.92} = 0.79 - 45.44\frac{(T_i - T_a)}{I}, \ R^2=0.98 \quad (9)$$

Consideration on relation of equation (7) to (9) found that the thermal efficiency of solar air heater with porous material would be higher than thermal efficiency of solar air heater without porous material. In whole cases, the thermal efficiency would be highest when difference of inlet air temperature and ambient temperature, (Ti – Ta), equal to zero. The thermal efficiency of solar air heater without porous material would be highest at 44%. Whereas, the thermal efficiency of solar air heater with porous material, compare with solar air hear without porous material, of porosity at 0.94 and 0.92 would be highest at 73% and 79%, respectively.

III Conclusions

The objective of this research to study thermal performance of solar air heater with and without porous material. The result found that difference of air temperature at inlet and outlet of solar air heater will be increased when solar radiation increased. Anyway, difference of air temperature at inlet and outlet of solar air heater with porous material will be higher than solar air heater without porous material and it will be higher when lower porosity. The thermal efficiency of solar air heater with porous material is higher than thermal efficiency of solar air heater without porous material. While, the thermal efficiency of solar air heater with porous material at lowporosity will higher than thermal efficiency of solar air heater with porous material at high porosity. Moreover, the thermal efficiency of solar air heater is increased with air mass flow rate increased. In addition, the thermal efficiency will be enhanced because of increasing of heat transfer area due to porous material.

IV. Acknowledgement

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List of Symbols

η	Thermal efficiency
q_u	Useful energy of solar air heater
c_p	Specific heat of air
T_i	Inlet air temperature
T_o	Outlet air temperature
T_a	Ambient temperature
A_c	Total surface area of solar air heater
I	Solar radiation intensity
F_R	Absorptivity factor
U_L	Overall heat transfer efficiency

Greek symbols

τ	Transmissivity coefficient
α	Absorptivity coefficient

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