A Study Thermal Efficiency of Solar Air Heater with Wire Mesh Stainless Installation: Using Solar Simulator

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Abstract This research was purposed to study thermal efficiency of solar air heater with wire mesh stainless installation. In experimental, solar irradiance for solar air heater testing was used solar simulator in the laboratory. This research consists of two main parts. First part: solar simulator testing. Solar irradiance used 4 halogen lamps with 1,500 W. The EN-12975-2 standard was evaluated the solar simulator performance for steady-state efficiency test. Experimental result, solar irradiance was good homogeneity at distance 70 cm with solar irradiated 980.4 W/m² and the uniformity value was lowest as 6.84%. It was suitable to test the solar air heater. Second part: a study thermal efficiency of solar air heater. Solar air heater performance was evaluated with the ASHRAE 93-86 standard. In experimental, wire mesh stainless was varied pores per inch (PPI) at 4, 8 and 12 PPI and constant layer at 11 layers. Air mass flow rate was constant at 0.037 kg/s and average solar irradiance about 980.4 W/m². A comparison between solar air heater with and without wire mesh stainless was conducted. It was found that, thermal efficiency of solar air heater with installing wire mesh stainless was increased and greater than without wire mesh stainless about 5.10 %, 16.75 % and 34.81 %, respectively.

1. Introduction
Solar air heater is a kind of heat exchangers that transform solar energy into heat. Usually, they are used for heating air in drying agricultural products and as an air heater in combination with auxiliary heaters for air conditioning of buildings [1]. Flat plate solar air heaters are non-adiabatic radiative heat exchangers; they are essentially used at low temperature levels (T<375 K) in air heating and drying systems [2]. Solar air heaters are simple devices to heat air by utilizing solar energy. Such heaters are implemented in many applications which require low to moderate temperature below 60 °C [3]. The main part of flat plate collector consists of: a case which holds a back insulation, an absorber and a transparent cover [4]. The transparent cover reduces heat losses towards the front, meanwhile the air flows in between the absorber plate and the thermal insulation. To increase thermal efficiencies, heat has to be transferred efficiently from the absorber to the flowing air [5]. Therefore, many configurations of the absorber plate have been designed to improve the heat transfer for the air flow in the passage. Velmurugan and Ramesh [6] was evaluated thermal performance of wire mesh solar air heater. The matrix solar air heater with a wire mesh produces higher thermal efficiency over the conventional flat plate solar air heater. Chabane, et al. [7] was studied heat transfer and thermal performance with longitudinal fins of solar air heater. Longitudinal fins were used interior the absorber plate to increase the heat exchange and render the flow fluid in the channel uniform. The maximum efficiency values obtained for the 0.012 and 0.016 kg/s with and without fins were 40.02,
51.50% and 34.92%, 43.94%, respectively. Anuradha and Oommen [8] were studied a v-groove solar air collector. The results showed that the collector efficiency is about 35%. Alvarez [2] was developed and evaluated efficiency of single-glass air solar collector with an absorber plate made of recyclable aluminum cans. The result was shown that, the efficiency was increased with using recyclable aluminum cans. The maximum efficiency reached was 74%. Rajendra Kava [9] was augmented heat transfer and friction in asymmetrically heated rectangular ducts with ribs on the heated wall in transverse, inclined, v-continuous and v-discrete pattern. It was found that, v-discrete pattern was highest thermal efficiency and lowest friction factor, transverse ribs pattern was lowest thermal efficiency, v-continuous ribs pattern was highest friction factor. Tanda [10] was studied heat transfer coefficient in rectangular channels with transverse and v-shaped broken ribs. Result was shown, heat transfer coefficient was increased with increased ribs high and heat transfer coefficient was higher than smooth flat plat solar air heater about 300 %. Benlu and Jiang [11] was studied heat transfer coefficient and friction factor of rectangular solar air heater with inclined ribs between 0 to 90 degrees. The result was, inclined ribs with 60 degrees was highest heat transfer coefficient and pressure drop. And inclined ribs with 20 degrees were highest thermal efficiency. 

From investigations, solar air heater is high thermal efficiency with increase heat transfer area but pressure drop and friction factor will be increase. For these reasons, the researchers will apply wire mesh stainless to increase heat transfer area. Because wire mesh stainless is a kind of porous media, it can absorb, emit heat and enhance heat transfer with absorber plate and air [12-15], and can reduce pressure drop and friction factor. Therefore, this research is proposing to install wire mesh stainless in solar air heater for increase thermal efficiency. The results of this experiment will be useful and guide development the solar air heater in further.

2. Thermal efficiency of solar air heater

The efficiency of a solar air heater is defined as the ratio of the amount of useful heat collected to the total amount of radiation striking the collector surface during any period of time.

\[ \eta = \frac{\text{SolarEnergyCollected}}{\text{TotalSolarStrikingCollectorSurface}} = \frac{Q}{I \times A_c} \]  

Useful heat collected for an air-type solar collector (solar air heater) can be expressed as:

\[ Q_c = \dot{m}C_p (T_{\text{air,out}} - T_{\text{air,in}}) \]  

So, thermal efficiency is calculated by Eq. (3)

\[ \eta = \frac{\dot{m}C_p (T_{\text{air,out}} - T_{\text{air,in}})}{I \times A_c} \]  

where \( C_p \) = Specific heat of air (kJ/kg K)  
\( \dot{m} \) = Mass flow rate of air (kg/s)  
\( T_{\text{air,out}} \) = Air temperature at outlet solar air heater (K)  
\( T_{\text{air,in}} \) = Air temperature at inlet solar air heater (K)  
\( A_c \) = Solar absorber area (m²)

3. Equipment and methodology

3.1 Equipment

3.1.1 Solar simulator design.

In experiment, solar irradiance used solar simulator in laboratory for solar air heater testing because some parameter can control such as solar irradiance, ambient temperature and ambient air velocity. Solar simulator frame made from box steel, solar irradiance used 4 halogen lamps with 1,500 W, shown in Figure 1. The EN-12975-2 standard was evaluated the solar simulator performance for steady-state efficiency test, because light field is the most important part of the solar simulator, an acceptable uniformity of irradiance in the irradiated surface and having stable irradiance over the time of test, are design factor of an authority light source for scientific aims [16]. The EN-12975-2 standard details were following [17]: The lamps shall be capable of producing a mean irradiance over the
collector aperture of at least 700 W/m². At any time, the irradiance at a point on the collector aperture shall not differ from the mean irradiance over the aperture by more than ±15% (uniformity value). The irradiation map is usually measured with an automated X-Y system that moves the reference pyranometer every 150 mm in both directions. The pyranometer is maintained about 20-30 seconds in each position.

Figure 1. a) Halogen lamps arrangement, b) 4 Halogen lamps with 1,500 W.

Figure 2. a) Consists of solar air heater: 1. Glass, 2. Aluminum plate (absorber plate), 3. Wood, 4. Fiber Glass, 5. Steel frames and 6. Zinc plate, b) Solar air heater with wire mesh stainless.

3.1.2 Solar air heater design. Solar air heater made from angle bar 1 m length, 0.7 m width and 0.1 m height. Solar absorber made from aluminum plate 1 m length, 0.6 width and black painted. On top of solar air heater was cover with transparent glass. Side and bottom was insulated with wood and fiberglass 0.02 m thickness, and cover outside with zinc plate, was shown in Figure 2a. Wire mesh stainless was installed inside of solar air heater, was shown in Figure 2b.

4. Methodology
Solar simulator in laboratory used to evaluate thermal efficiency of solar air heater. The solar simulator performance was evaluated with the EN-12975-2 standard and solar air heater performance was evaluated with the ASHRAE 93-86 standard. The schematic diagram of solar collector testing with solar simulator was shown in Figure 3. Before the thermal efficiency evaluated, solar air heater was exposed in solar simulator about 30 minutes and collected data at 5 hours [5]. Air was flow through the flow straightener at solar air heater inlet with blower for reduce air swirl. Air mass flow rate was measured with the hot wire anemometer, air temperature was measured with type K thermocouple at 15 positions of air flow through solar air heater, 3 positions of solar absorber plate, shown in Figure 4 and solar irradiance (I) was measured by pyranometer. Experimental data were collected with data logger at interval 10 minute for 5 hours. Solar air heater with wire mesh stainless...
was varied pores per inch (PPI) at 4, 8 and 12 PPI and wire mesh stainless layers constant at 11 layers. Air mass flow rate was constant at 0.037 kg/s each experimental. The experimental result would analyze and compare between solar air heater with and without (PPI=0) wire mesh stainless.

![Schematic diagram of solar air heater testing with solar simulator.](image1)

![Temperature measurement positions on solar air heater.](image2)

5. Experimental result

5.1 Solar simulator
Solar simulator used 4 halogen lamps with 1,500 W to generated solar irradiance. The EN-12975-2 standard was evaluated the solar simulator performance for steady-state solar air heater efficiency test. From experimental result, it was found that solar irradiance was increased with decreased distance between halogen lamp and solar air heater. The solar irradiance was good homogeneity at distance 70 cm and the uniformity value was lowest as 6.84%. The solar simulator was provided maximum and minimum solar irradiance as 1,036.5 W/m² and 918 W/m², respectively and average solar irradiance was 980.4 W/m², shown in Figure 5. Therefore, this solar simulator was suitable for evaluate solar air heater thermal efficiency.

![Solar simulator irradiated distributions (I, W/m²).](image3)

5.2 Solar air heater thermal efficiency
A comparison between solar air heater with and without (PPI=0) wire mesh stainless with varied pores per inch (PPI) at 4, 8 and 12 PPI and constant layer at 11 layers. Air mass flow rate was constant at 0.037 kg/s and average solar irradiance at 980.4 W/m². From result, it was found that solar air heater without wire mesh stainless was provided thermal efficiency at 48.24% and hot air outlet average temperature at 40.37 °C, shown in Fig 6a.
Experimental result of solar air heater with wire mesh stainless installation, it was found that thermal efficiency was higher than without wire mesh stainless. Thermal efficiency and air temperature was increased with increased wire mesh stainless PPI. Because an installing wire mesh stainless inside solar air heater was an increasing heat transfer area and wire mesh stainless was a kind of porous media, it was absorber and emitter and can enhanced heat transfer from solar irradiance to...
the air flow through wire mesh stainless. Therefore, air temperature and thermal efficiency was increased. A result was shown in Figure 6 and 7.

From Figure 7, solar air heater with installing wire mesh stainless at PPI=12 was provided highest thermal efficiency about 65.04% and air outlet average temperature about 41.40 °C. A comparison between with and without wire mesh stainless it was found that, wire mesh stainless at PPI=4, 8 and 12 can increased thermal efficiency about 5.10 %, 16.75 % and 34.81 % greater than without wire mesh stainless, respectively.

6. Conclusions
A study thermal efficiency of solar air heater with wire mesh stainless installation. Solar simulator was constructed and tested in laboratory with EN-12975-2 standard. The solar irradiance was good homogeneity at distance 70 cm and the uniformity value was lowest about 6.84% and provided average solar irradiance about 980.4 W/m².

An evaluated thermal efficiency of solar air heater it was found that, the solar air heater with wire mesh stainless was greater than without wire mesh stainless and at PPI=12, 11 layers was provided highest thermal efficiency about 65.04% and greater than without wire mesh stainless about 34.81%.

References
[1] Alvarez G, Arce J, Lira L and Heras MR 2004 Sol. Energy. 77 107
[2] Ajam H, Farahat S and Sarhaddi F 2005 Int. J. of thermodynamics 8(4) 183
[3] Alta D, Bilgili D, Ertekin C and Yaldiz O 2010 J. of Applied Energy 87 2953
[4] Kurtbas I and Durmus S 2004 Renew. Energ. 29 1489
[5] Pottler K, Sippel CM, Beck A and Fricke J 1999 Sol. Energy. 67(1–3) 35
[6] Velmurugan P and Ramesh P 2001 Indian. J. Sci. Technol. 4(1) 12
[7] Chabane F, Moummi N and Benramache S 2014 J. Adv. Res. 5 183
[8] Anuradha A and Oommen R 2013 J. Sci. Eng. Res. 4(6) 2072
[9] Karwa R 2003 Experimental, Int. Comm. Heat. Mass. Transfer. 30(2) 241
[10] Tanda G 2004 Int. J. Heat. Mass. Transfer. 47 229
[11] Benlu and Jiang PX 2006 Exp. Therm. Fluid. Sci. 30(6) 513
[12] Tongtem P and Jakjai S 2009 Conf. of the mechanical engineering network of Thailand 22 (Thailand)
[13] Mital R, Gore JP and Viskanta R 1997 Combust. Flame. 111 175
[14] Boonmak S, Chavaratsinthorn N and Krittakom B 2013 Thailand Renewable Energy Community Association Conference 9 (Thailand: Chiangmai)
[15] Srisuwan P, Chavaratsinthorn N and Krittakom B 2013 2013 Thailand Renewable Energy Community Association Conference 9 (Thailand: Chiangmai)
[16] Sabahi H, Tofigh AA, Kakhki IM and Bungypo-Pard H 2016 Sustainable. Energy. Technol. Assess. 15 35
[17] Kovacs P 2012 A guide to the standard EN 12975 (Technical Research Institute of Sweden)

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