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To cite this article: Hu Jiayu and Jin Chengjun 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **556** 012020

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Experimental study on thermal performance improvement of solar air heater using piezoelectric fan

Hu Jiayu¹, Jin Chengjun¹

¹College of architecture and environment, Sichuan University, Chengdu ,No.24 South Section 1 Yihuan Road. Zip:610065

Abstract. This paper presents experiment research about piezoelectric fan array in solar air heater (SAH) at the frequencies 45-60Hz by using lamp array as solar radiation simulator. The effectively heat transfer coefficient (HTC) of the traditional method such as strip rib on the solar collector and enhancement by piezoelectric fan are compared in detail with different mass flow rate of the air. A prototype solar collector with dimension of 300(L)×150(W)mm is fixed in a wind tunnel in the experiment. Three configurations of piezoelectric fan array have been tested, the results show that the piezoelectric fan can increase the HTC effectively, the HTC is increased 3-3.5 times compared with smooth plate and the additional power consumption of the piezoelectric fan as low as 0.6W for 2×2 piezoelectric fan array, whereas for the pressure drop of the SAH increased no more than 5%. The resonance frequencies of the two types of piezoelectric fans in experiment are 55Hz and 53Hz respectively, the maximum amplitude and the HTC achieved at the resonance frequency. It's an effective way for SAH application compares to other methods of heat transfer enhancement in SAH and rarely be reported in the area of SAH.

Keywords: Single&double flow; Solar air heater; Piezoelectric fan; Heat transfer enhancement; Thermal performance; Pressure drop

1. Introduction

Solar air heaters(SAH)is the popular device to utilize the solar energy. There are two types of SAH which include single and double pass mode[1], according to the airflow path around the solar absorber plate. The SAH may be further classified into four basic configurations are: a front-pass collector, a back-pass collector, a front and back pass collector and a through-pass collector. How to increase area or heat transfer rate of the absorber is the principal problem of the SAH design and optimization. Numerous methods for heat transfer enhancement and area increasing have been researched. The most popular extend surface is rib in SAH. The geometrical parameters of rib roughness have a significant influence on heat transfer and fluid friction, Anil Kumar Patil [2] reviewed a variety of artificially roughened solar air heater and suggested that transverse rib roughness produces maximum heat transfer enhancement, and lightweight can be achieved by multi V-rib roughness geometry. Alam[3] et al. researched effect of circularity of perforation holes in V-shaped blockages on heat transfer and friction characteristics of rectangular solar air heater duct. Other shape of the obstacles are also have been researched ,Bekele[4] et al. have proposed a research about delta shaped obstacles in SAH and concluded the thermo-hydraulic performance of the presented SAH is higher than those in previous studies. Some researchers are also investigate the optimization problem of the SAH. Yang, Ming et al.[5], presented numerically method to optimize the offset strip fins of the SAH. Bouadila et al [6]et al. gave the energy and exergy by using first law and second law to analysis solar air heater with latent heat storage and obtained the optimization energy and exergy efficiencies. Some researcher performed the experiments by using solar simulator, numerous methods to simulate



the heat flux from solar were applied in literature. P Velmurugan et al [7] investigated different absorber surface geometries by using halogen lamp as solar simulator and got average radiation 645 W/m², whereas M. Zukowski et al [8] used infrared lamp to simulate the solar and investigated thermal and flow characteristics of microjet air solar heater.

As mentioned above, most of the methodologies and researches of the heat transfer enhancement in solar air heater are passive method, namely, by increasing the heat transfer area or insert some extend surface to generate turbulence. Unfortunately, all of these methods will increase the pressure drop of SAH dramatically and lead to a lower overall energy efficiency. A piezoelectric fan or PE fan is new methodology in heat transfer enhancement, especially with the low power consumption. A PE fan is a flexible cantilever beam, and the vibration of the fan is actuated by piezoelectric material. There are plenty of studies about PE fans in literatures, especially in optimization of the location of the PE fans. Mark Kimber et al [9] gave the maximum heat transfer coefficient of the single PE fan and conducted that the heat transfer enhancement is only relate to amplitude and frequency, whereas the more effect to HTC as for the frequency; Ten times more efficient in converting the input power to useful energy compared to axial fan. Abdullah, M. K. et al.[10],[11],[12] investigated PE fans using CFD software and particle image velocimetry (PIV) system, the research conducted that the ratio of the height of PE fans from heat source to length of PE fans, tip gap, amplitude of vibration etc. are all critical factors and the related optimized values of these parameters was given by their research.

Although there are so many works in PE fans and SAH but the combination study about two subjects is rarely, this work will focus on the application of the PE fans in solar air heater, the capability of heat transfer enhancement by using PE fans in SAH has been demonstrated by using wind tunnel and lamp array. The experimental study has been presented with three different PE fan configurations.

2. Experiment apparatus and procedures

The experiment apparatus is composted by four sections: wind channel, absorb plate, heating element and measurement unit. The wind channel is made by plywood, acrylic and glass, the length of channel is 710mm, the interior cross section of the channel is 150mm×150mm, it include a glass window on the top of the channel for simulate the solar radiation with the dimension of 300mm×150mm and same as the absorber plate, the absorber plate is fixed in the middle of the channel, it can be replaced by different type absorber plate. Five different absorber plate are used as described in Figure 1. Three types of absorb plate used in experiment which the PE fans was fixed on board as heat transfer enhancement element. All of board are aluminium with black anodized, the finished absorber plate shown in Figure 2. The inlet temperature and outlet temperature is measured by two groups T type thermocouple. The air volume flow rate and system resistance is measure by wind tunnel system (Longwin 9266SR) which accordance to AMAC 210-07 standard[13].

The heating element includes eight Philips R63 reflector infrared bulbs with the power of 40W each for solar heat simulation and powered by 220V AC. The energy intensity was measured by infrared power meter (LS122) and the intensity is 3337W/m². Although the energy intensity is higher than some literatures but it is not affection to compare the heat transfer performance of the difference set-up, the more effective absorber plate will lead to higher heat transfer efficiency and higher temperature rise of the air under the same experimental configuration.

The air was sucked from ambient with the temperature of indoor by variable exhaust system, variation of the flow rate was performed by using variable frequency drive controlled by Longwin 9266SR, the air pass through the absorber plate and the temperature raised. Measurements of air volume flow rate were done using nozzles in 9266SR and static pressure differences was also recorded for preparing flow characteristics.

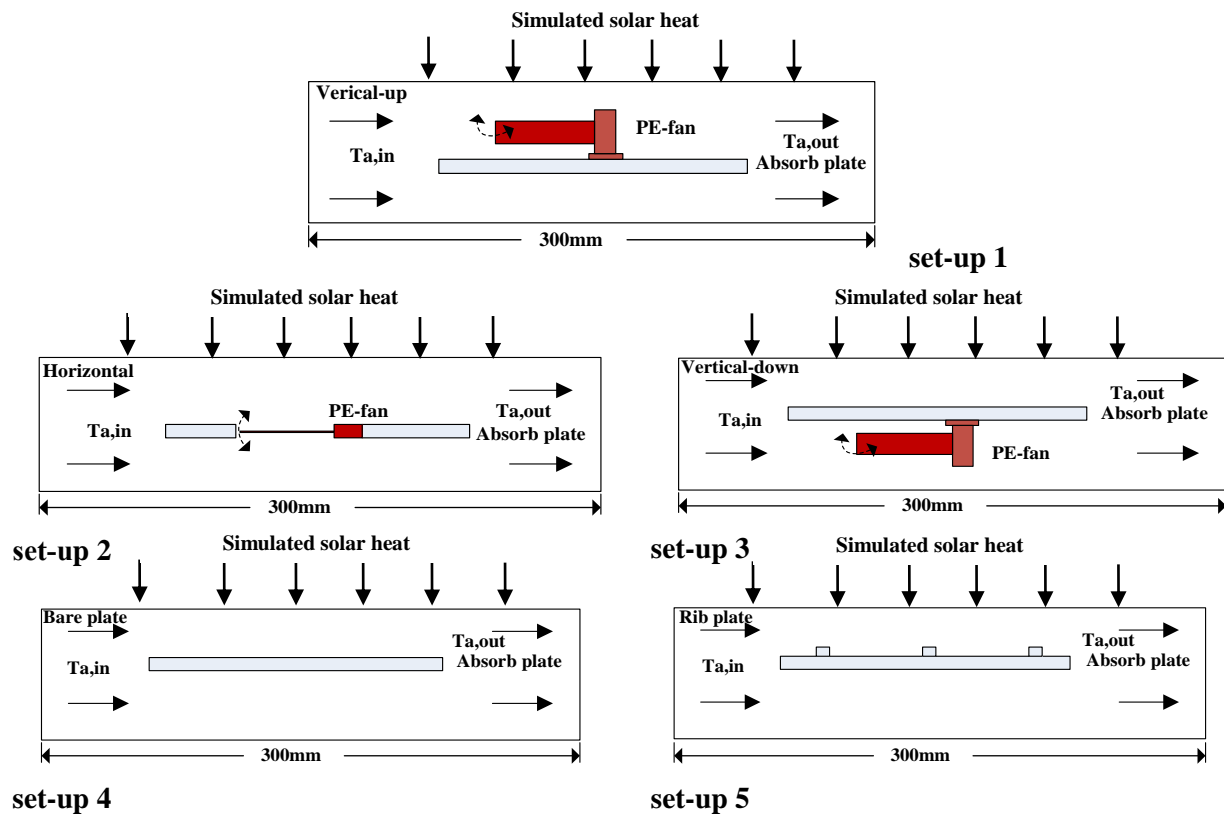


Figure 1. Five types of absorber in wind channel



Figure 2. The photo of four absorber plates used in experiment

The different pressure drop acquired by different absorber plate, different mass flow rate and different frequency of the PE fan. The experimental tests include a series of measurements, system pressure drop vs. volume flow rate was performed automatically with the Longwin 9266SR and the temperature difference was recorded by Agilent 34970A datalogger. The volume flow rate Q_a range from $40\text{m}^3/\text{h}$ to $162\text{m}^3/\text{h}$ ($40.5\text{ m}^3/\text{h}$, $81\text{ m}^3/\text{h}$, $121\text{ m}^3/\text{h}$, $162\text{m}^3/\text{h}$) corresponding the air speed 0.5m/s , 1m/s , 1.5m/s , Q_f is the total heat gained by air.

3. Experiment results and discussion

Three set-ups of PE fans and two benchmark set-ups were used in experiment as previously described, the temperature rise and the heat dissipation with the different configuration was prepared as shown in Fig 3 ~Fig5. The benchmark group are also presented in these charts. The highest air temperature rise is 7°C of set-up1 and higher than set-up 2, set-up 3 and benchmark set-ups.

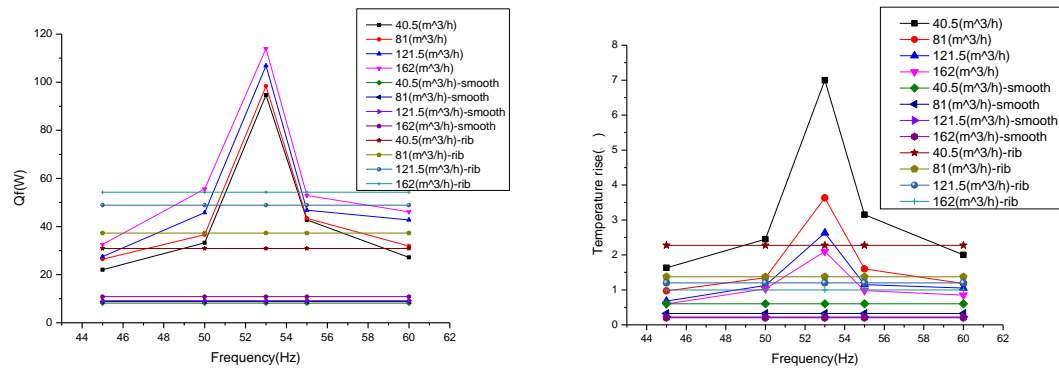


Figure 3. Heat gain and temperature rise of experimental set-up 1

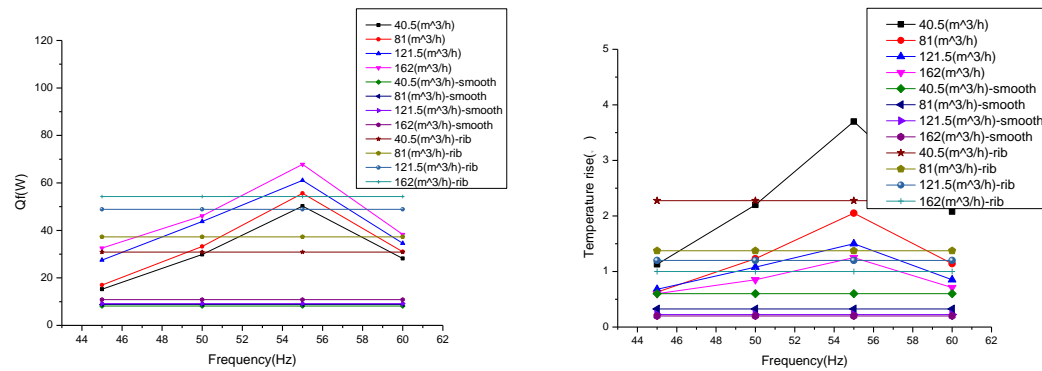


Figure 4. Heat gain and temperature rise of experimental set-up 2

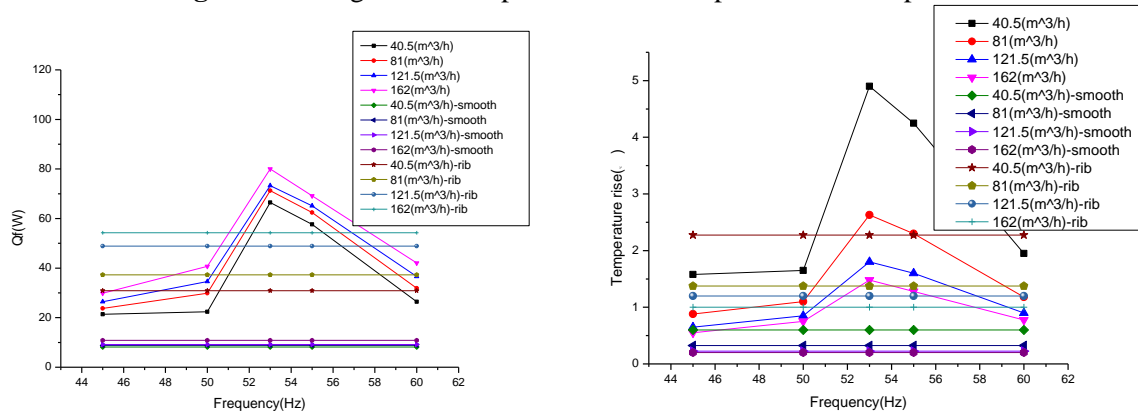


Figure 5. Heat gain and temperature rise of experimental set-up 3

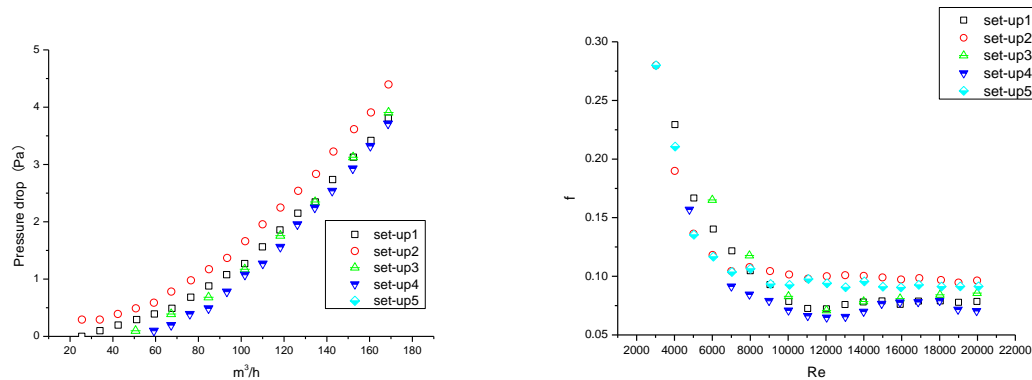


Figure 6. Pressure drop and friction factor of the different set-ups

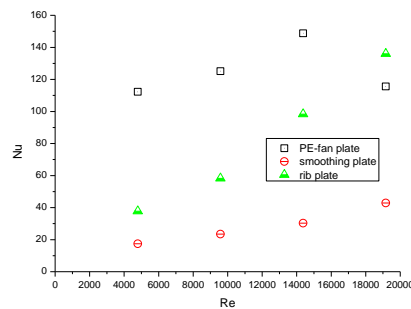


Figure 7. Comparison the Nu of the smooth absorber plate and PE fan enhancement absorber plate(set-up3 at the resonance frequency)

The highest heat transfer quantity or temperature rise was acquired at the resonance frequencies of each set-up. In the same PE-fan set-up, higher frequency always brings higher heat transfer rate. The reason may be that the boundary was disturbed by the vortex of the PE fans and the higher vibration may lead to higher turbulence than the lower frequency. The set-up1 is superior to any other set-ups in our works. The set-up1 and set-up3 have different heat transfer rate, although they are all vertical configuration of PE fan. The cause the difference is because that the top glass cover with the high temperature for most of the long wave spectrum were absorbed hence that the vortex generated by PE fan enhanced the heat transfer not only for absorber plate cover but also for the top glass cover for the set-up 1, whereas absorber plate heat transfer was enhanced only for the set-up 3. The heat transfer coefficient was calculated using the vertical down (set-up 3) for the reason that PE fans enhanced heat transfer of absorber plate only in the set-up 3. The result is more conservative and reasonable for set-up 3 considering the main aim of our work is to investigate the heat transfer enhancement of the absorber plate.

The pressure drop of the five set-up was prepared as shown in Fig 6 and the measurement were taken at the resonance frequency (excepted the benchmark group). The set-up 2 with the horizontal configuration has the highest pressure drop and set-up 4 has the lowest pressure drop without any heat transfer enhancement device. The pressures drop of set-up 1 and set-up 3 higher slightly than smooth plate (set-up 4) whereas highest heat transfers performance. The set-up 1 and set-up 3 have almost the same pressure drop for the symmetry configuration. As shown in Fig 6, the friction factor also has the same trend. Fig 7 and Fig 8 presents the PE-fan significantly increased the heat transfer coefficient comparison the smooth absorber plate and traditional method such as rib in SAH. Nusselt number is increased approximately 2-2.5 times corresponded the Re range from 15000~20000 compared with the Rahmati Aidinlou's[14] experiment.

Rahmati[14], Velmurugan[7], Zukowski[8] are all used the solar simulator to measure the efficiencies of solar air heater. We used the infrared lamp for the cost consideration but the distance to the glass cover is short and with small thickness of the top glass cover. These measures in our experiment are meant to increase the absorbed energy of the middle absorber plate and get more reasonable results about the heat transfer performances. The efficiency of SAH varied with the solar intensity according to [7], the higher solar intensity are always the higher temperature rise. But a little affection for the heat transfer coefficient calculate of the absorber plate, because of the higher heat flux lead to higher surface temperature.

The independent parameters in this work are inlet and outlet temperatures, absorber plate temperature, pressure drop of the channel, pressure drop of the flow meter nozzle and simulated solar radiation, T-type thermocouple with accuracy 0.1°C, pressure gauge with 0.05% accuracy, pressure difference gauge with 0.06% accuracy and infrared power meter 4% accuracy were used. The heat transfer coefficient is $\pm 4.29\%$, volumetric flow rate is $\pm 1.45\%$.

4. Conclusion

An experimental investigate was conducted to demonstrate the heat transfer enhancement of

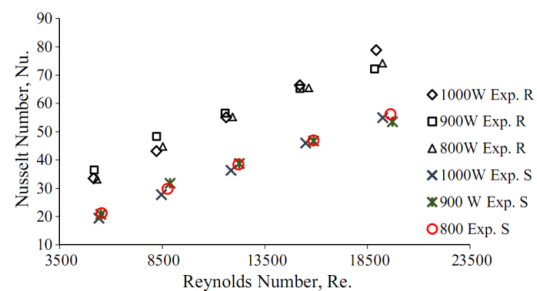


Figure 8. Comparison between the Nu versus Re in Rahmati Aidinlou's[14] experiment

steady state SAH by using PE fan, thermal and hydraulic characteristics of the prototype have been developed. There are three type of set-ups absorber plate in this work. These absorber plate were designed, constructed and tested under the same experiment configuration with varied mass flow rate, varied drive frequency and same simulated solar intensity. The heat transfer coefficient or Nusselt number increased 3-3.5 times by using the PE fan compare to the smooth absorber plate and increased 2.5 times compare to the traditional roughness absorber plate in literatures. The peaked heat transfer coefficient is acquired at the resonance frequencies of the PE-fan and the higher driver frequency can accompany the higher temperature rise and higher heat transfer coefficient. The pressure drop of the vertical set-up PE fan increased slightly and no more than 5% compared to other heat transfer enhancement measures. Therefore, the horizontal set-up PE fan has the highest pressure drop within our work. It can be conclude that PE fan is an effective way for SAH application compares to other methods of heat transfer enhancement.

Acknowledgments

The author would like to thank special work by Mr Li Yuxian for his experiment fixture design.

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