UNIVERSITI PUTRA MALAYSIA

BEHAVIOUR AND PERFORMANCE EFFICIENCY OF SOLAR AIR HEATER WITH IMPINGING JETS ON CORRUGATED PLATE

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By

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October 2017

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Energy is a subject of vital importance because of our great dependence on it in all aspects of life including the social sphere, the economy, agricultural and industry. Solar energy is one of the most promising renewable energy sources in the world. Solar radiation has potential for drying purposes and space heating. Solar collectors are employed to convert incident solar radiation into thermal energy. Solar air heaters are extensively used due to minimal used of materials, simple design, less maintenance, less corrosion and few leakage problems. On the other hand, air type solar collectors have two inherent disadvantages, low thermal capacity of air and a low absorber to air heat transfer coefficient. Therefore, this research is motivated by the need to study and develop a new solar air heater. Thus, the primary objective of this study is to analyses the behavior of the solar air heater with jet impingement on a corrugated absorber plate and compares its performance efficiency with a conventional solar air heater by determine the factors affecting the performance of the SAH, than design, simulate, and validate experimentally the new novel design for the SAH, using indoor tests. Numerical and experimental analysis was used to achieve the aforementioned objective. Building the mathematical model of the proposed design using MATLAB software to predict the thermal performance of the SAH, followed by validation experimentally using indoor test. The results showed that the thermal performance of the solar air heater system with jet impingement on a flat plate absorber is better than the solar air heater cross corrugated plate without a jet however, the solar air heaters system with a jet impingement on corrugated plate have higher thermal performance efficiency of approximately 7%. The agreement between experimental results and predicted results was shown in most cases, of 500-1000 w/m^2 solar radiation. Good agreement was achieved between the simulation and the experimental data. Thus, it can be concluded that the increment in solar air heaters efficiency is higher with the corrugated absorber due to addition vortexes, and because of reduced influence of the jet air velocity on the heat transfer coefficient at the lower

flat absorber plate since the turbulence increases at the corrugated absorber for fixed mass flow rates of air and channel widths.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KEBERKESANAN DAN KEBERKESANAN PEMAKANAN SURGA SATUR SOLAR DENGAN MENJADI JET PADA PLATE YANG DIPERLUKAN

Oleh

ALSANOSSI MOHAMED ABOGHRARA

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Tenaga adalah subjek yang penting kerana kebergantungan kita terhadapnya dalam semua aspek kehidupan termasuk bidang sosial, ekonomi, pertanian dan juga industri. Tenaga solar adalah salah satu sumber tenaga terbarukan paling menjanjikan di dunia. Sinaran suria mempunyai potensi untuk tujuan pengeringan dan pemanasan ruang. Pengumpul suria digunakan untuk menukar radiasi sinaran matahari kepada tenaga haba. Pemanas udara solar digunakan secara meluas kerana penggunaan bahan yang minimum, reka bentuk yang lebih mudah, kurang penyelenggaraan, kurang kakisan dan masalah kebocoran yang sedikit. Sebaliknya, pengumpul solar jenis udara mempunyai dua kelemahan yang wujud, kapasiti udara terma yang rendah dan penyerap rendah untuk pekali pemindahan haba udara. Penyelidikan ini termotivasi oleh keperluan untuk mengkaji dan membangun sebuah pemanas udara solar baru. Untuk menganalisis tingkah laku pemanas udara solar dengan pelepasan jet pada plat penyerap beralun dan membandingkan kecekapan prestasi dengan pemanas udara solar konvensional. Penyelidikan kini mengambil berat tentang meramalkan keberkesanan prestasi haba tiga jenis sistem pemanas udara solar, melalui simulasi matematik, melalui sistem pakar berasaskan MATLAB yang boleh digunakan sebagai alat untuk menyokong reka bentuk pemanas udara solar..Walaupun prestasi haba sistem pemanasan udara solar dengan pelepasan jet pada penyerap plat rata hanya sedikit lebih tinggi daripada pemanasan udara solar silang salutan beralun tanpa jet, tetapi sistem pemanas udara solar dengan pelanggaran jet pada plat beralun mempunyai kecekapan prestasi haba yang unggul. Dan persetujuan antara hasil eksperimen dan hasil yang diramalkan ditunjukkan dalam kebanyakan kes. Keputusan simulasi adalah sangat dekat dengan data eksperimen.

Walau bagaimanapun, dari hasil eksperimen dapat disimpulkan bahawa kenaikan dalam kecekapan pemanas udara solar adalah tinggi dengan penyerap beralun kerana penambahan vorteks, dan kerana pengaruh pengurangan laju udara jet pada pekali perpindahan haba, pada penyerap rata yang lebih rendah plat sejak peningkatan pergolakan pada penyerap bergelombang untuk kadar aliran jisim tetap lebar udara dan saluran. Jadi udara menyerang permukaan bawah plat penyerap dan memecahkan lapisan sempadan termal permukaan. Ini menyebabkan kenaikan dalam pekali perpindahan haba, yang membawa kepada peningkatan dalam kecekapan pengumpul berbanding penyerap plat rata.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

L	length of heater (m)
W	width of heater (m)
H_g	mean gap thickness between the absorbing plate and the jet plate (m)
A_a	absorber area (m^2)
A_h	heater area (m^2)
d_j	jet diameter (m)
I	solar- insulation rate incident on the glass cover (W/m^2)
V_w	wind velocity of the ambient air (m/s)
τ_c,	transmissivity of solar radiation of the glass cover
α_{ap}	absorptivity of solar radiation of the absorbing plate
η	Efficiency of the air heater.
S	solar radiation absorbed by the absorbing plate per unit area, (W/m^2)
m_f	Air mass flow rate per unit area of heater.(Kg/s)
q_u	useful energy gain (W/m^2)
c_p	specific heat of air (kJ/Kg.K)
T_a	temperature air flowing through channel above bottom plate (K)
T_f	temperature air flowing through channel above jet plate (K)
T_{o1}	outlet air temperature through jet, above jet plate (K)
T_o	outlet air temperature through heater (K)
T_{ap}	mean temperature of absorbing plate (K)
T_c	mean temperature of the glass cover (K)
T_A	ambient temperature (K)
h_w	convection heat-transfer coefficient from glass cover due to the wind (W/m^2K)
$h_{r,\,c-s}$	radiation heat-transfer coefficient between the cover and the sky. (W/m^2K)

$h_{c,\ f\text{–}bp}$ thermal convection by fluid to bottom plate (W/m^2K)

$h_{c,\ ap\text{–}f}$ thermal convection by absorbing plate to the fluid (W/m^2K)

$h_{r,\ ap\text{–}bp}$, thermal radiation by absorbing plate and the bottom plate, (W/m^2K)

$h_{r,\ ap\text{–}c}$, thermal radiation by glass cover to absorbing plate (W/m^2K)

$h_{c,\ ap\text{–}c}$ thermal convection by glass cover to absorbing plate (W/m^2K)

k_i thermal conductivity of the insulation (W/m K)

b mean thickness of the insulation.(m)

SACs solar air collector system

η_{therm} thermal efficiency

EFF effect efficiency test

MSE Mean Square Error

CHAPTER 1

INTRODUCTION

1.1 Background

During the past decade, the increased costs for the fossil fuels used for drying purposes have led to a search for alternative methods that consume less fuel energy. Solar energy is one of the most promising renewable energy sources in the world; it is the world's most abundant permanent source of energy.

According to Yatim, (1999) , the amount of solar energy intercepted by the Earth is 170 trillion kW; 30% of this amount is reflected to space, 47% is converted to low temperature heat and reradiated to space, and 23% powers the evaporation precipitation cycle of the biosphere, where less than 0.5% of this energy is presented in the kinetic energy of wind and waves and in the photosynthesis storage in plants. Compared to fossil fuels, solar energy is non-polluting, has no moving parts to breakdown, and does not require much maintenance Kangtragool, (2003).

Solar collectors are employed to convert incident solar radiation into thermal energy at the absorbing surface, and then transfer this energy to a fluid (commonly water or air) flowing through the collector Thakur, (2014). Solar air heaters use air as the transporting fluid. They are extensively used in industrial and agricultural applications without optical concentration.

The solar air heater has minimal use of materials and the direct use of air as the working substance reduces the number of required system components, resulting in a simpler design and less maintenance together with less corrosion and fewer leakage problems compared to liquid solar systems Shariah (2002), Hou (1999) On the other hand, air type solar collectors have two inherent disadvantages i.e. the low thermal capacity of air and a low absorber to air heat transfer coefficient Hetsroni (2012).

Consequently several studies to determine the thermal performance of solar air heaters have been conducted, theoretically and experimentally, and different modifications have been suggested and applied to improve the heat transfer coefficient between the absorber plate and air as seen in Figure 1.1. Norton (1995), Mudawar (2009)Yeh (1999).

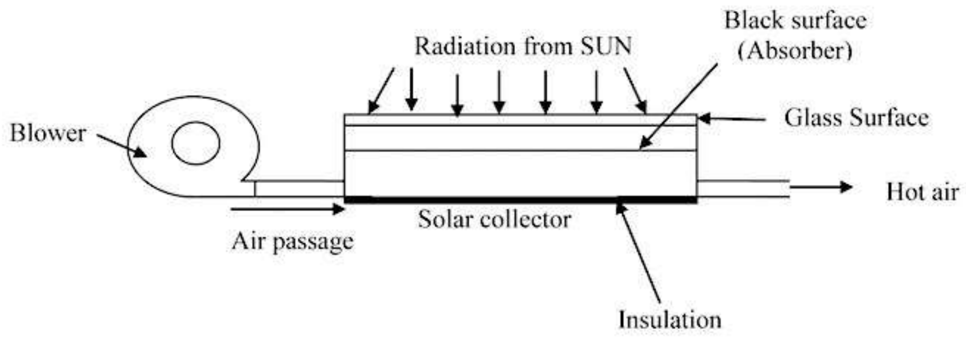

Figure 1.1 : Solar air collector

In Malaysia, the analysis of solar radiation in several main towns shows that solar radiation has the potential to be used for drying purposes and other applications Rotich (2014). Typically, open air sun drying has been used to dry plants, seeds, fruits, meat, wood and other agricultural and forest products. For large scale production, limitations of open air drying have surfaced Yeh (1999). The advantages and disadvantages of the solar air heater system are discussed in the following sections:-

1.1.1 Advantages

1. Better absorbance of solar energy without the restriction of direct solar gains in comparison to typical solar passive technologies,
2. Better timing of solar heat with the usage of a thermal wall; when there is no sunshine heat is released from the wall,
3. Solar air heater system reduces the costs of energy consumption for the building.
4. In comparison with water collectors no chemicals for antifreeze are needed and in case of damage they do not cause any loss for the building.
5. Solar air heater system can cooperate with HVAC systems (heating, ventilation and air conditioning), for example for preheating air.
6. Solar air heater system can be utilized for very low energy residence and commercial, institutional buildings.

1.1.2 Disadvantages

1. Very small heat capacity in comparison with water (air=0,0003 kWh/m^3K; water=1,16 kWh/m^3K), Rosen (2010)
2. The need for handling a large volume of air due to its low density.
3. Air cannot be used as a storage fluid because of its low thermal capacity.
4. In the absence of a proper design, the cost of solar air heaters can be very high.
5. The poor heat transfer properties of air. Special care is required to improve the heat transfer from absorber to air.

1.2 Problem Statement

Many solar collector designs have been used currently for the fulfillment of the different requirements in developed and rural areas. The solar air system is a type of system which collects solar energy and transforms it into heat. It has an important place in solar thermal systems and is widely used in many commercial applications such as in buildings, agriculture and industrial drying Hamdan (2005).

Application for Solar Air Heater: The heated air that solar air heater produce can be used for:

•Industrial: Air pre-heating for combustion processes that means thousands of applications Drying minerals, coal, paper, bricks, and food industry products. Especially the drying of brown coal would be very important for power plants.

•Agricultural purposes: Crop drying: grains, fruit, vegetables, and meat.

Important benefits can be gained by harvesting the crop early and drying it with solar heat to protect it from rodents, and mildew. and to free the land for a second, brief crop space heating for greenhouses, warehouses and animal farms. Fruit and other produce dryers.

•Household purposes: Space heating small driers, Space heating for warehouses, and factories.

However, a lot of equipment and appliances need to have high heat transfer performance to guarantee the quality and capability of their process Lin (2006), & Cheng (2011). So, in any heat exchanger, a higher overall heat transfer coefficient is desirable. Flat plate solar air heaters are generally used for low and moderate temperatures. However, the solar air heater (SAH) has a low efficiency, due to the low convective heat transfer coefficient in the smooth absorber surface Prasad (1983), Han (1984), SinghS (2011), air limitation to energy extraction Chauhan (2013) and the mass flow rate of air limitations Verma (2000), Alsanossi (2016).

This makes it necessary to develop new techniques to enhance the heat and mass transfer in an SAH, and free heating system, free ventilation in a building, free dry buildings by hot air obtained from sun energy

So far, numerous research and development aspects concerning heat and mass transfer enhancements have been discussed extensively in the literature. One of the effective ways to enhance the convective heat-transfer rate is to increase the heat-transfer surface area and to increase the turbulence inside the channel by using roughened surfaces Goldstein (1976), & Goldstein (1977) and many studies have been carried out on these aspects.

The performance of SAHs depends upon the physical design of the collectors, the heat losses, the air circulation rates, and the prevailing ambient conditions Ammari (2003). Although solar air collectors are a very important component in solar drying Parker (1993), & Karim (2004), there is limited work on the effect of the air flow passage dimensions on the efficiency and pressure drop.

(Chauhan & Thakur, 2014b) reported that the current highest value of the effective efficiency of SAHs is about 34 to 58%. A lot of equipment and appliances need to have a higher efficiency to meet the quality and capability of their process. It is found also that the heat removal factor of the corrugated duct collector is improved considerably by an average value of 59%, while its efficiency is enhanced by 15-43%.

To increase the thermal performance of a SAH, heat has to be transferred by adopting efficient techniques. So far, there is limited on the utilization of the jet impingement and corrugated absorber concurrently in SAH designs, either theoretically or experimentally. Therefore this study will apply jet impingement at a corrugated absorber of a SAH. This proposed design is expected to enhance significantly the turbulence and heat transfer rate of the new SAH. Use different parameters sash as solar radiation, mass flow rate and ambient temperature, to get optimize performance.

1.3 Objective

This research is motivated by the need to study and developing a new SAH. And analyses the behaviour of the SAH with jet impingement on a corrugated absorber plate and compares its performance efficiency with a conventional SAH. The specific objectives of the research are:

1. To determine the factors affecting the performance of the SAH, the all parameters, and their prospects and limitations in order to suggest a new novel design for the SAH.
2. To design and simulate the SAH by using jet impingement with a corrugated plate for higher thermal efficiency.
3. To validate experimentally the performance of the mathematically optimum design of the SAH collector using indoor tests.

1.4 Expected Outcome of the Study

The expected outcome of this research is a proposed design that will enhance significantly the turbulence in the duct of a SAH and its heat transfer rate. It will also produce a newly developed mathematical model for the proposed design. The mathematical modeling can be used for predicting the thermal performance of the three types of SAH. The mathematical modeling should be of interest to designers, engineers and students who can use the model for tutorials, and to consumers who like to compare different SAH configurations.

1.5 Scope of the Study

The main drawback of an air heater is that the heat transfer coefficient between the absorber plate and the airstream is low, which results in a lower thermal efficiency of the heater. Hence, several modifications are suggested and applied to improve the heat transfer coefficient between the absorber plate and air.

Currently market in the active solar air heater has this two design they are the cross-corrugated absorber plate SAH and the SAH design with jet impingement on a flat plate absorber, and get good efficiency. This propose to combined this two previous SAH designs and development third module to see how the efficiency of new design.

This study focuses on solar air heaters and their corresponding mathematical modeling and subsequently on developing a program that could be used as a tool to design and predict the thermal efficiency

1.6 Hypothesis

For this purposes, a number of simplifying assumptions were made to lay the foundations without obscuring the basic physical situation. These assumptions are:

i. The thermal performance of a SAH is a steady state.
ii. The sky can be considered as a black body for long wavelength radiation at an equivalent sky temperature.
iii. Loss through the front and back of air at the same ambient temperature.
iv. Dust and dirt on the heater and shading of the absorbing-plate are negligible.
v. Thermal inertia of the heater components is negligible.
vi. Operating temperatures of the heater components, and mean air temperatures in the air channels are all assumed to be uniform.
vii. The temperature of the air varies only in the flow direction.
viii. Thermal losses through the heater backs are mainly due to conduction across the insulation; those caused by wind and thermal radiation of the insulation are assumed negligible.
ix. The holes of the jet plate are circular
x. There is a negligible temperature drop through the glass cover, absorber plate and bottom plate.

1.7 Thesis Layout

This thesis is divided into seven chapters. Chapter One focuses on the research problem, the objectives and the expected outcome of the study. Chapter Two is the literature review and Chapter Three focuses on the methodology of the study. Chapter Four discusses the theoretical considerations of the developed mathematical model. Chapter Five focuses on the experimental investigation while Chapter Six focuses on the results and discussion. Finally, Chapter Seven presents the conclusions and recommendations.

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