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Matrix solar air heaters – A review

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ABSTRACT

Improvement of thermal performance of a solar air heater can be obtained by enhancing the rate of heat transfer. Thermal efficiency of matrix solar air heater is higher in comparison to conventional type. Number of studies has been reported in the literature on the performance of matrix air heater with different material packing and elaborated various parameters such as design; heat transfer enhancement, flow phenomenon and pressure drop in the duct. Majority of the studies revealed an increase in the thermal efficiency for matrix collector as compared to conventional plane solar air heater. This review paper presents an extensive study of the research carried out on matrix solar air heater. Based on literature review, it is concluded that the solar air heaters performed well when packed with porous medium and this is due to the geometrical parameters of porous material. In addition double pass porous bed solar air heaters performed better than single pass. Various types of matrix materials used in the literature and correlations developed for heat transfer and friction factor by different researchers have been presented. Much attention has been devoted in this paper to portrait the development of various types of solar air heaters over the years. The merits and demerits of different models evolved by many researchers have been critically analyzed. Finding in a nut shell is that the drawbacks associated with conventional nonporous solar air heaters such as high heat loss to the ambient, decreased convective heat flow from plate to air, etc. can be overcome by the use of an effective design of porous bed solar air heater.

Contents

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1. Introduction

The dwindling in nature of fossil reserves and the increasing demand for energy in various forms, urged the search for alternative resources. The renewable energy resources received prominent attention in recent years, as it is proven to be a viable alternative of conventional energy sources. Solar energy which is available for free of cost in almost all part of the world is a non-polluting reservoir of fuel. The simple and effective way of utilizing solar energy is to convert it into thermal energy for heating application by using solar collectors. Solar air heater is basically a flat plate collector used for generating hot air for applications such as crop drying, industrial process heating, space heating, timber seasoning etc., [1,2]. The drawbacks of conventional solar air heaters are heat loss to the ambient and poor heat convection from absorber plate to the air stream [3,4]. Several designs have been developed to address the heat losses from the solar air heater.

The development in the solar air heating system around the globe since 1877 was presented by Saxena et al. [5]. The Selective black coating on the flat plate collector improves the performance of solar air heater [6]. The use of selective material as an absorber plate can be avoided using a fully developed turbulent flow [7]. In a flat plate collector where the flow is not turbulent the radiation effect is greater in which the surface mean temperature is very important. The convective heat transfer is more relevant in an air heater with turbulent flow, in which the absorber mean temperature is reduced. The radiation effect is low in such cases [8]. The efficiency of air heaters depend on design and operating parameters like number of channels [9,10], flow channel depth [11,12], velocity of air [13] etc. Enhancement of convective heat transfer coefficient from the absorber plate to fluid plays pivotal role in improve the efficiency of solar air heaters. This can be attained by improving the fluid turbulence. By aiming for a better fluid turbulence, several modifications in the air flow duct are studied such as introducing fins, baffles and artificial roughness on the absorber plate [14,15]. Review on artificial roughness were presented by many researchers [16–20]. Even though artificial roughness is an attractive mode to enhance the heat transfer from the absorber plate but it is economically not feasible for larger production of air heaters. There has been a significant research interest in packed-bed absorbers for solar air heaters because of its distinct advantages over conventional flat-plate collectors. The absorber temperature of a porous matrix is assumed to be almost equal to the temperature of the air stream in solar matrix air heater caused by the high volumetric heat transfer coefficient [4]. Several researchers theoretically and experimentally studied the performance of matrix solar air heater for betterment in efficiency. A general analysis for a matrix collector was carried out and solutions for the equations were given by Singh and Bansal in 1983 [21]. But their analyses were commented by Sugget in the year 1984 and pointed out the drawbacks of the method adopted [22]. N.K. Bansal highlighted the importance of matrix air heater in drying application [23]. Gupta and Garg [24] studied the performance of air heater by packing its duct with wire mesh between glass cover and galvanized iron sheet. Different types of studies on porous type solar air heaters were reported such as thermal performance of porous type solar air heater with black coated packing, without coating, without packing [25], and exergy analysis of packed bed collector [26–29]. Numerical calculations are done by using different boundary conditions and also considering the realistic case of different air and matrix temperatures [30]. Hassab and Sorour [31] discussed the effects of air flow rate, scattering, optical thickness, thickness and conductivity of matrix type solar air heater. Performance of matrix air heater was tested under constant flow conditions by Bharadwaj et al. in the year 1981 and found the efficiency reduced from an initial value of 38.9% [32]. Studies on thermal performance of double pass solar air heater with packed bed [33] reported that there is a considerable enhancement in the thermal efficiency of solar air heater when packed with porous material as compared to the conventional flat plate absorbers and the increased performance of these types of air heaters depends on the geometrical parameters of the wire mesh [34–36].

The primary aim of this review paper is to discuss in detail about several matrix type solar air heaters developed so far and analyzes of their performances. Optimized values of geometrical and operating parameters reported by various researchers are listed here. The present study made a classification of various matrix materials used and their efficiencies compared each other. The correlations developed for heat transfer and friction factor for various geometrical and operating parameters of matrix solar air heaters are discussed here. Besides, the present study shares sufficient information on matrix solar air heaters developed so far and paves way for further research.

2. Performance of solar air heater

Thermo hydraulic performance helps to design an energy efficient solar air heater. Thermal performance deals with the heat transfer in the duct while thermo hydraulic performance gives idea about the pressure developed in the duct. The following equations enable one to calculate the thermal and thermo hydraulic efficiency of matrix solar air heater.

2.1. Thermal performance

A simplified model of solar air heater is depicted in Fig. 1 and the energy balance on different components of a conventional solar air heater is represented in Fig. 2. Thermal performance of solar air heater can be evaluated by the following equation given by Duffie and Beckman [37] which gives the useful heat gain when I is the intensity of solar radiation, F_R and U_L are the collector heat removal factor and overall heat loss coefficient respectively.

$$Q_u = A_c F_R\left[I(\tau\alpha)_e - U_L(T_i - T_a)\right] \quad (1)$$

or

$$q_u = \frac{Q_u}{A_c} = F_R\left[I(\tau\alpha)_e - U_L(T_i - T_a)\right] \quad (2)$$

The rate of heat transfer is given by the following equation

$$Q_u = \dot{m}C_p(T_o - T_i) = hA_c\left(T_{pm} - T_{am}\right) \quad (3)$$

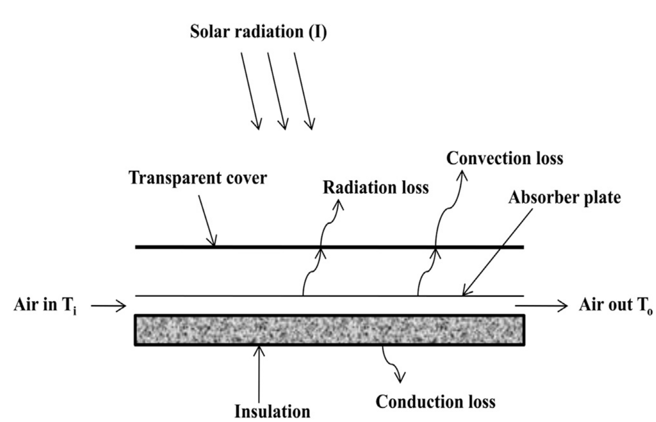

Fig. 1. Schematic representation of conventional solar air heater.