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Development and Testing of Forced Convection Solar Air Heater for Industrial Applications

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Abstract: Energy and material saving considerations, as well as economic motivation have led towards developing an energy efficient solar air heater. in order to enhance the performance of the air heater, different turbulence generators such as ribs, baffles and delta winglets have been proposed. in this project work, a pin-fin based flat plate solar heater has been developed and compared its performance under two different configurations (configuration 1- without pin-fins and configuration 2 with pin-fins). the performance of the solar air heater has been evaluated under different climatic conditions of coimbatore city in india with different air mass flow rates. based on the performance comparisons, the air flow rate through the solar air heater is optimized.

Introduction

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^{o}c. the main applications of a solar air heater are domestic, industrial and agriculture purposes. the drawback of solar air heaters are the need for handling larger volumes of air than liquids due to the low density of air as a working substance with low thermal capacity of air. however, the efficiency of solar air heaters is low due to low prandtl number of air and low absorber to air heat transfer coefficient. the most important advantages for air-type collectors includes no freezing, boiling or pressure problems; generally lower weight and low construction cost. There are different factors affecting the solar air heaters efficiency, e.g. collector length, collector depth, type and shape of absorber plate, number of glass cover plate, wind speed, etc. several investigators have attempted to design more effective solar air heaters by changing the design characteristics, the applications of solar air heaters or using various collector types. on the other hand, the energy equations alone do not encounter the internal losses; it cannot be a sufficient criterion for the solar air heater efficiency. but, the second law analysis, exergy, is more informative with regard to the optimum operating zone, quantifying the inefficiencies, their relative magnitudes and locations. exergy is the maximum work potential that can be obtained from a form of energy. exergy efficiency is more realistic than energy efficiency and that exergy analysis should be considered in the evaluation and comparison of the solar thermal system. therefore, the consideration of this study will be on the detailed energy and exergy analysis of different designed flat-plate solar air heaters for evaluating performance and optimizing the designed heater with the maximum exergy efficiency under given operating conditions.

Energy which is available in various forms plays a vital role in sustenance of life. in recent years, energy consumption rate has increased manifold with the growth of world population, urbanization and industrialization. continuous use of fossil fuels or conventional energy resources

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would eventually lead to the exhaustion. due to the world's depleting fossil fuel reserves, nonconventional energy resources have started playing a prominent role. solar radiation, one of the renewable energy sources is available as a green and inexhaustible source of energy. they can be utilized as thermal energy for heating purposes. solar air heaters are one of the applications considered very important and widely used for drying of crops and space heating. due to its simplicity in nature at low and moderate temperatures, it is very popular for low temperature applications. thermal performance of solar heaters is an area of concern for researches worldwide. one of the methods of improving the performance is by increasing the heat transfer coefficient between the absorber plate and air.

Various methods of enhancing the heat transfer rate of solar air heaters have been studied and applied. Many investigators used artificial roughness of different shapes and sizes for increasing the heat transfer rate and thereby improving the performance of the solar air heater. in this paper, an attempt has been made to review the different artificial roughness geometries, turbulators viz. ribs, perforated baffles/block/ribs, obstacles and delta winglets. the pin fins are used in this experimental setup for increasing performance.

Problem identification

In order to meet the hot air requirement in industrial applications, a forced convection solar drier will be suggested. the two major problems identified for this work are

1. high grade electric energy is used for producing heat.
2. losses due to excess air flow through the absorber surfaces.
3. more heat loss from the absorber surface due to lack of air contact in absorber surface.

To overcome these drawbacks, a forced convection solar drier is proposed in this work. in order to enhance the performance of a solar air heater, pin-fins are introduced. to evaluate its performance, a forced convection solar drier will be developed. it will be tested under the meteorological conditions of coimbatore city in india.

Solution

The following points are the solutions for above identified problems

1. pin-fins are introduced to improve the contact area
2. flow rate of air is to be optimized.

Experimental setup

A schematic diagram and its photographic view of a forced convection solar drier integrated heat enhancing materials are depicted in the Figure: 1 and Figure: 2, respectively. the solar air heater consists of a flat plate solar air heater of area $2m^2$ (2m × 1m) integrated with pin-fins, centrifugal fan of 200 w. the solar air heater has 2 mm thick copper absorber plate coated with black paint to absorb the incident solar radiation. a 5 mm thick tempered glass was placed above the absorber plate to increase the temperature of the air by green house effect. a 25 mm gap was provided between the glass and the absorber surface for air circulation. the gap between the absorber surface and the glazing surface was filled with machining scraps to enhance the rate of heat absorption. one side of the collector was connected to the blower with the help of reducer and the other side was attached with a reducer with flow measuring arrangement. the solar air heater was tilted to an angle about 25^o with respect to horizontal. the system is oriented to face south to maximize the solar radiation incident on the solar collector. on the basis of measurements, coimbatore (latitude of 10.39^o n, longitude of 77.03^{o}e), where the experiment was conducted has about 10 hours of sunshine, but potential sunshine duration was about 8 h per day only.

Drawing

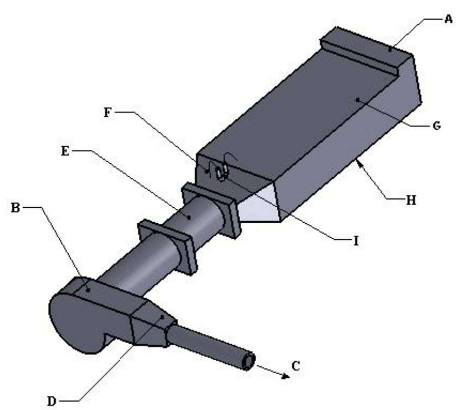

Figure: 1 Experimental setup of the solar air heater

a → anemometer with reducer
b → blower
c → hot air to the required space
d → air diffuser
e → air chamber
f → reducer
g → glass cover
h → absorber plate
i → manometer

Experimental procedure

The air blower is switched on and the air flow rate through the flat plate solar air heater was adjusted to 0.025kg/m^{2}s with the help of control valve. solar intensity was measured using solar intensity meter. the temperature of air flows over the absorber plate gets enhanced due to the presence of pin-fins. temperatures at typical locations as shown in the Figure: 1 were measured. all the experimental observations were made at one-hour interval. the experiments were conducted only 9 h per day. based on the experimental observations, the energy and exergy performance are to be evaluated.

Conclusion

Many investigators have concluded that the energy efficiency of the solar air heaters is further improved by increasing the area of exposure of absorber surface. following conclusions are drawn based on the literature review

1. Pin-fins play a major role in improving the thermal performance of the solar air heater.
2. The size of the pin-fin and mass flow rate of air through the air heater is to be optimized.
3. different arrangements include fixing of wires (transverse, angled, v-shape, multi v-shape, w-shape and discrete etc.), groove formation by machining process, expanded metal mesh ribs, metal grits and creating dimple shaped geometries.
4. Transverse rib at different angle further enhances the heat transfer due to movement of vortices along the rib and formation of a secondary flow cell which results in high heat flow region near the leading end.
5. It is found in the literature that perforated blocks/baffles are thermo-hydraulically better in comparison to solid blocks/ baffles because perforation in blocks/baffles enhances the nusselt number due to elimination of hot spot just behind the ribs.
6. Delta winglets generate the vortexes which increase the heat transfer without much increase in friction factor in solar air heater or heat exchangers.

7. Thus there is tremendous scope for future study of the heat transfer and friction factor characteristics of perforated ribs/blocks/ baffles/winglets in different arrangements such as angled, v-shape, multi v-shape and w-shape etc.
8. Based on the literatures, a pin-fin type absorber plate is proposed. the performance of the plate is theoretically increased.
9. The experimental calculations are proposed in future work.

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