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EXPERIMENTAL INVESTIGATION ON DOUBLE-PASS SOLAR AIR HEATER WITH INTERNAL HEAT STORAGE

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Abstract - Solar energy is one of the crucial energy sources for agricultural drying, industrial process heat and space heating requirements, that is renewable as well as pollution-free. In drying applications and heating of the building spaces, solar energy has an important role to play, as it provides an enormous amount of heat energy where the air is the final receiver of the heat energy. Flat plate collectors are good enough for heating air, but the technology and applications of solar air collectors have not been so developed as a liquid solar collector. As solar energy is inconsistent and nature dependent, more often there is a mismatch between the solar thermal energy availability and requirement. This drawback could be addressed to an extent with the help of thermal energy storage systems combined with solar air heaters. The solar air heaters typically have single-pass type airflow, having flow over or under or both over and under the absorber plate. Double- pass type solar collectors will have flow over the absorber plate for the first pass and returns under the absorber plate for the second pass or vice-versa.

Key Words: Wireless Sensor Networks (WSNs), Energy-efficient techniques, Clustering algorithm, Routing protocol, Load balancing.

INTRODUCTION

A nation's economic growth directly depends on energy production and its utilization. The available energy should be easily available, environment friendly and affordable for the long-term. As the availability of fossil fuels is limited, there is a need for exploring new sources of energy. Fossil fuel consumption throughout the world increases steadily and rapidlyPollution is one more factor that forces researchers to discover new environmentally friendly energy resources and conversion techniques. These two issues are addressed by renewable energy sources to an extent. Almost all renewable energy sources are pollution-free but many limitations associated with these sources limit dependency as a frontline energy source. Advancements in renewable energy conversion techniques increase the usage of these sources in substitute for fossil fuels.

1.2 SOLAR ENERGY POTENTIAL IN INDIA

India is gifted with immense solar energy potential. India receives about 5,000 trillion kWh per year of solar energy over India's terrestrial area. Average solar radiation of 4-7 kWh/m2 /day is received in most parts of India. If a very small portion of total incident solar radiation is captured that can meet the entire power requirements of the country. The estimated energy output from all the energy reserves in India can easily be met by one full year's solar energy collection.

2.LITERATURE REVIEW

The solar energy-based drying and hot air supply prove to be a promising means for most of the agriculture and building heating needs. Apart from the above-mentioned applications, the hot air from solar devices serving in industrial process heat necessities as well. In this literature review, the research and review articles on solar air heater designs, heat storage systems in solar air heaters, analytical and numerical models on the thermal performance of collectors and solar air heater applications in different fields have been conferred. The researcher or prospective user of these systems must consider several factors while studying the suitability of the systems for a particular application. The likely parameters are thermal and thermo-hydraulic performance, the initial and operational cost of the system, lifetime, maintenance and ease of installation. The thermal performance of the collectors is reported in detail along with its application. The review also brings out the measurement systems for solar collectors and different mathematical models for single and double-pass solar air heaters.

2.1. Solar Air Heaters

The generally used solar air heaters make use of the forced convection principle between the absorber plate and the flowing air. In certain applications, the natural convection type of solar air heaters is employed. The flat plate collector's heat transfer ability mainly depends on the absorber plate design. There are many kinds of solar air heating systems that were designed and used for heating needs. The important research in the field of basic solar air heaters was reviewed in this section. Arunkumar et al. (2019) reviewed solar air heaters with different designs for the enhancement of their thermal performance. The poor thermal performance of the conventional solar heaters initiates the need for artificial modifications on the absorber plates. As a result, the laminar sub-layer above the absorber plate was transferred to the turbulence layer which in turn increases the heat transfer rate. The study reported all the different types of flow field modifications, flow conditions and heat transfer rates for air heaters. Ravi & Saini (2016) stated the solar air heaters make use of the highly absorbing and conducting plate called absorber to harness the thermal energy from solar radiation. The gaseous heat transfer fluid, like air, is passed over or under this absorber plate to gain the heat. The air flows along with the absorber for once and leaves the collector system in a single-pass collector. On the other hand, in two-pass collectors, the air passes over the absorber and at the end, it takes the opposite direction to flow below the absorber plate such that it passes through the absorber plate for about double the time compared to single-pass systems. The different techniques adopted with double-pass collectors to improve the thermal conversion efficiency were presented in this study.Mzad et al. (2019) fabricated and tested a single pass flat plate air heater with double glazing. The experimentation is carried out to optimize performance parameters like surface azimuth angle and tilt angle. The results showed that tilt angles between 15º and 30º were gained maximum solar radiation. The experiments were conducted for a yearlong and tilt angles above 45º resulted in lower solar radiation reception. Jongpluempiti et al. (2017) fabricated a single pass solar air heater for assisting a spray dryer. A blackened galvanized steel plate was used for the absorber plate. The tilt angle was maintained at 15º which resulted in a maximum absorber surface temperature of 83.9℃ and outlet air temperature of 52.5℃ during noontime. The solar air heater is used along with a spray dryer in order to reduce electricity consumption. This showed about 30 kWh reduced energy consumption and a payback period of 34 days. Gill et al. (2012) investigated a single glazed low-cost solar air heater that gives a better thermal efficiency during the summer while double glazing is best during the winter for all flow rates. For the 0.020 m3 /s mass flow rate per m2 of collector area, the maximum average thermal efficiency was 37.45% and 24.07% for the single and double glazed solar air heaters respectively during the summer. The corresponding figures for the winter were 30.29% and 45.05% respectively. For the same flow rate, the maximum rise in air temperature was 18℃ and 12℃ for the single and double glazed solar air heaters respectively during the summer. The same figures for the winter were 19.5℃ and 33.5℃ respectively.

2.2 OBJECTIVES OF THE RESEARCH WORK

The objectives of the present research work are presented below based on the understanding from the literature survey and the observations from the tea industries. The objective of this research is,

1. To enhance the thermal performance of the solar air heater by introducing new configurations and modifications to the conventional flat plate solar air heater.

2. To study the effectiveness of the integrated sensible heat storage and porous materials which are low-cost and easily available, in the solar air heater.

3. To determine the pressure drop across the collector and thermohydraulic efficiency of the solar air heater with fins and baffles.

4. To compare the experimental results with the theoretical model and with similar research works.

5. To perform a feasibility study of a solar air heating system for tea industries in the Nilgiris district for the tea withering process.

2.3. MATERIALS AND METHOD

The performance of the conventional SAH is found to be very low due to the development of the viscous sub-layer closer to the absorber plate surface. Developing artificial roughness on the absorber plate reduces this viscous layer and forms the arbitrariness in the air adjacent to the absorber plate surface (Ravi & Saini 2016). In this study, to examine the performance of the DPSAH, four different cases of counterflow DPSAH without and with roughness geometry on each absorber plate have been studied experimentally. The collector is constructed in such a way that, provision was made to replace the absorber plate as and when needed. The solar collector is also provided with a space for storing heat storage materials and porous medium in the bottom channel. Three different types of finned and baffled absorber plates are developed and compared with a flat absorber plate based on the research gap found in the literature survey. The various types of absorber plates developed and tested are listed below,

1. Flat absorber plate (Type I)

2. Absorber plate with longitudinal fins (Type II)

3. Absorber plate with perforated discontinuous baffles (Type III)

4. Absorber plate with perforated V-baffles (Type IV)63

Apart from the different absorber plates, the DPSAH is also provided with the following sensible heat storage and porous materials for performance enhancement.

1. Crushed stone heat storage material (CS HS)

2. Granite heat storage material (GR HS)

3. Granular carbon heat storage material (GC HS)

4. Machined chips porous material (MC PM)

5. Crown caps porous material (CC PM)

3.1 DOUBLE-PASS SOLAR AIR HEATER (DPSAH) SETUP

A single-glass cover double-pass solar air heater (DPSAH) with provision for having thermal storage materials is shown in collector box was fabricated with 1.8 cm thick plywood. The solar collector is 1m long, 0.5 m wide, and 0.275 m deep. The upper channel is having a 10 cm height and the lower channel is having a 17.5 cm height which includes the space for the heat storage materials. The inner surfaces of the solar collector are coated in selective black colour to maximize solar energy absorption. The absorber plates are designed to have 0.9 m long and 0.5 m wide, resulting in a collector area (Ac) of 0.45 m2 . The absorber plate is made up of a 0.5 mm thick copper plate. A gap of 100 cm is maintained at the end of the absorber plate to enable the air to return for the second pass. Insulation was provided below the heat storage area with a 20 mm thick Glass wool (Wadhawan et al. 2018). A 4 mm thick toughened single-glass cover was provided to minimize convective heat loss from the absorber plate to the surrounding (Abdullah et al. 2018).

In general a wireless sensor network contains thousands of sensor nodes. The sensor nodes can communicate between

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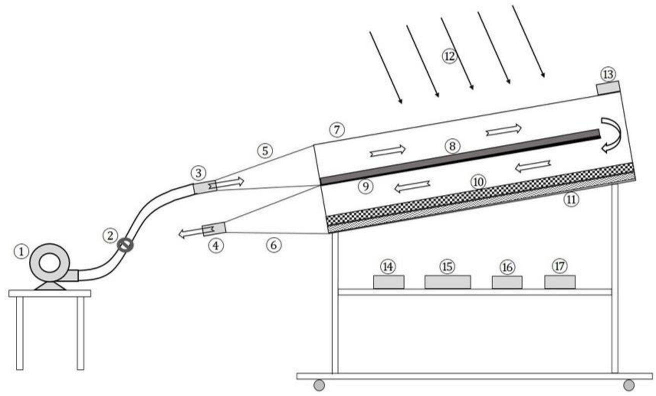
4.1 RESULTS AND DISCUSSION

This chapter presents the outcomes of the investigational study on the different configurations of the double-pass solar air heater. The experiments were performed between May 2018 and November 2019. The listed experiments were executed in the fabricated experimental setup defined in the previous chapter. The various configurations of DPSAH are examined in the city of Coimbatore, 11.02 °N latitude and 76.96 °E longitudes, in southern India. The flat plate solar collector was studied with 4 different types of absorber plates (i.e. flat plate absorber plate, longitudinal fins attached absorber plate, perforated discontinuous baffles attached absorber plate, and perforated V-baffles attached absorber plate) and five different sensible heat storage and porous materials. The experiments are started at 8.30 AM and continued till the time when there is no rise in inlet air temperature is observed at the outlet. For the day time thermal analysis, the readings were considered between 9.00 AM and 4 PM. The readings and measurements were recorded at a time interval of thirty minutes during this period. The effectiveness of the heat storage materials was examined after sunshine hours, that is, between 04.00 PM and till the time when there is no rise in air temperature is recorded. During this period, the data were recorded every 30 minutes. To avoid the abnormalities related to the solar radiation and local wind velocity, each experiment is conducted for two days and the average of these two days data



were used for interpretation. Depending on the data collected all required plots are drawn to compare the results suitably.

4.2 RESULTS OF DOUBLE-PASS SOLAR AIR HEATER WITH FLAT ABSORBER PLATE (TYPE I)

4.2.1 Solar Intensity Pattern

The experiments are conducted in the days when the solar intensity values followed a similar pattern, in general. There are few days in which the experiments were discontinued halfway due to drastic changes in

the solar intensity during the sunny hours. The solar intensity was recorded

every thirty minutes to ensure the uniform pattern of solar intensity. The solar

intensity increased from morning until noon, at that point it reached the

maximum value, and then slowly decreased until sunset. As mentioned earlier,

each experiment was conducted for two days and the average of the readings

was presented and plotted.

5.1 TEA PRODUCTION METHODS

One of the objectives of this work is to emphasize a technique of reducing fuelwood dependency in the processing of tea in India. This study intends to assess the possibilities and likely benefits of implementing flat plate SAH in the tea industries in and around the Nilgiris district of Tamilnadu state in India. The withering and drying processes in the manufacturing of tea require thermal power and it is commonly obtained from the combustion of fuelwood. However, the availability of fuel woods is scarce nowadays, which leads to higher fuelwood costs as demand rises.

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