Potential of Solar Steam Generator Based on Evacuated Tube for Heating and Humidification

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Abstract—*Renewable energy has been used in various forms for more than a century. Environmental issues like global warming, pollution and depletion of non-renewable energy source marks the importance of ecofriendly renewable sources of energy. Evacuated Tube Collector is an alternative way to utilize solar energy in form of heat over conventional fuel. It receives solar radiation and constitutes a proven source of heat energy for domestic applications and various industrial. Many research works have been carried out in the past to utilize solar radiation for different application using Evacuated Tube Collector. However it seems that no work has been carried out by researchers for heating and humidification using Evacuated Tube Collector as heat source in Indian climatic conditions. This paper focused on potential of solar steam generator based on evacuated tube for heating and humidification. The present experimental set-up consisting of 40 evacuated tubes, a header and a duct. Water in the header is heated up and converted to steam by using solar energy collected by the evacuated tubes. Steam was generated for 3 hours from 13:00 to 16:00 hours. The generated steam from the collector is mixed with the ambient air flowing through the duct. The air flow-rate was fixed at 52.31 kg h-1. The condition at the outlet of the duct is recorded after every half an hour. The maximum temperature difference and humidification rate of 6 ºC and 0.580 kg h-1 was obtained at 14:00 hours respectively. The results show great potential of evacuated tube collectors for winter air conditioning.*

Keywords—Solar Air-Conditioning, Evacuated Tube Collector, Heating and Humidification, Winter Air-Conditioning

I. Introduction

Evacuated Tube Collector constitute a proven origin of thermal energy for industrial and domestic process heat and power generation, However their implementation has been powerfully influenced by economics. In recent years, environmental issues and other geopolitical factors have centered attention on renewable energy resources, improving the prospects for Evacuated Tube Collector deployment. Further work is needed to increase the system efficiencies and active areas of research taking account of the testing rig design, development of advanced heat receiving elements and working fluid, optimization of reflector structures, thermal storage device and direct steam generation (DSG).

Solar energy has turn out to be one of the most favorable alternative energy resources as it is free, environmental friendly and also it is available in abundance. A large part of industrial process heat lies from low to medium temperature range which can be supplied by solar energy [4]. From the last few years, solar energy is utilized in the field of moderate temperature applications using various types of collector such as, parabolic trough collector parabolic dish collector, and evacuated tube collector.

The first solar thermal collector designed for building roofs was patented by William H. Goettl and called the "Solar heat collector and radiator for building roof to use solar energy using low cost operation which can be used for domestic application India.

II. Literature review

This work focuses on solar steam generator based on evacuated tube for heating and humidification or winter air-conditioning. Traditional winter air-conditioners works on high grade energy like electricity. The demand for electricity is increasing with rising population, industrialization and modernization. Developing countries find themselves short in meeting this constantly increasing demand. Most of the power plants still uses fossil fuels to produce electricity. These fossil fuels are at the verge of extinction; again burning of these fuels cause environmental problems like air pollution, soil pollution etc. The above reasons are forcing us to find an alternative energy source which is renewable and non-polluting. Solar energy being the most potential and clean energy has attracted scientists through decades. Following are some of the studies carried out on evacuated tubes till date. A study was carried out to calculate the solar radiation received by cylindrical absorber inside evacuated tube [Richard Perez., Robert Seals.]. A study was carried out to co-relate the natural flow of fluid inside a single ended evacuated tube collector the result showed that the natural circulation can be co-related with collector inclination, solar intensity, tank temperature and aspect ratio of the tube [I. Budihardjo et al.]. Developed different heat extraction methods for evacuated tubes also numerically studied water circulation behavior in single ended evacuated tube [G.L. Morrison et al.]. Evacuated glass tube was investigated numerically and experimentally. The results showed that the performance was related to shape of absorber, incidence angle of radiation and arrangement of tubes [Yong Kim., TaebeomSeo.]. Thermal performance of evacuated tube is evaluated using energy equation also influence of air between copper and absorber tube on efficiency is studied [Liangdong Ma.]. Studied optimal tilt angles for different types of evacuated tubes and found that tilt angle has to be less than latitude angle [Runsheng Tang.,]. A setup was fabricated for air heating with evacuated tubes; it was also integrated with phase change material [SurajMehlia., AkashYaman.,]. Investigated the thermal performance of the individual glass evacuated tube solar collector by analytical method [Liangdong Ma]. Presented a recently developed concept for evacuated tube collector or storage(ETC/S) system containing a phase-change material (PCM). To serve as the PCM, commercial-grade paraffin wax was placed inside evacuated tubes equipped with heat pipes. Experiments were performed to assess the impact of paraffin application on the thermal performance of the ETC/S system [Feliński and Sekret (2016)]

The objective of this work is to investigate evacuated tube collector for heating and humidification of air which is required for achieving human comfort conditions in winter season (cold and dry environment).

III. Experimental setup

Solar steam generator based on evacuated tube for heating and humidification is shown in figure 1. The system consists of 40 evacuated tubes attached to a header. The high head of the header opens to the duct. A blower is attached to the duct as shown in figure. Evacuated tubes and header are inclined at 5o and 15o from the horizontal respectively. The header and the forty evacuated tubes are filled with 80 liters of water. Two photographic view of the setup is shown in figure 2 and 3. The main components of the system are as follows.

IV. Evacuated tubes

Evacuated tubes are made up of two co-axial borosilicate glass tubes fused at one end. The dimensions of the tubes are inner diameter 37 mm, outer diameter 47 mm and length 1500 mm each. There is vacuum between the two layers of the glass to reduce the heat transfer loss. The outer tube is transparent and has high transmissivity. The outer surface of the inner tube is coated with a layer of aluminum nitride (Al-N/Al) this coating has high absorptivity and less emissivity.

V. Header

Schematic diagram of the header is shown in figure 4. The header is fabricated from a steel box of dimension 120 mm x 120 mm x 1500 mm. This header is insulated with polystyrene from all sides to decrease the heat loss. The thickness of the insulation is 50 mm. A safety valve is attached to the low head of the header. A pipe was provided at the high head of the header for steam outlet.

VI. Duct

A newly designed duct is fabricated for this setup. The schematic diagram of the duct is shown in figure 4. It is made of polyvinyl chloride material. The duct has length of 750 mm and diameter of 58 mm. Blocks of polystyrene material is fixed inside the duct as shown in figure to ensure proper mixing of steam with the flowing air.

VII. Measuring devices and instruments

In this experiment the data recorded were temperature of water at low head and high head of header, ambient dry bulb and wet bulb temperatures, duct outlet dry bulb and wet bulb temperatures and solar radiation. The air flow rate was kept constant. Solar intensity was measured by Pyranometer which has range of 0 W m-2 to 1400 W m-2 and accuracy is± 2 W m-2. Dry bulb and wet bulb temperature was measured by PT100 RTD Temperature sensor having 0℃ to 200℃ range and accuracy is ± 0.3 ℃. Air velocity is measured by Anemometer with range 0 m s-1 to 45 m s-1 and accuracy is ± 2 %.

VIII. Experimental procedure

The setup was exposed to the sun one day before the readings were taken. Natural circulation of water taking place in header and evacuated tubes are shown in figure 5. Water in the evacuated tubes are heated up by the energy received from the sun. Due to this heating and inclination of tubes, thermo-syphon effect is created in tubes thus hot water from pipes moves to the header and cold water from header rushes into the tubes. The inclination of the header from horizontal forces hot and less dense water to the top of the header. The hot water at the high head of header gets converted into steam. This steam is then carried into the duct by the steam pipe. The steam gets mixed with the flowing air in the duct thus heating and humidifying the flowing air.

IX. Performance indexes

The performance of the system is measured in terms of its COP (coefficient of performance) which is the ratio of the energy gained by the air to the solar energy received for that duration(dt). Where ma is mass of air, $h1$ is enthalpy of ambient air, $h2$ enthalpy of air at outlet of duct, I is solar intensity and A denotes collector area.

X. Results and discussion

The experiment was carried out with Indian location [29° 58´ (latitude) North and 76° 53´ (longitude) East] on 6th of February 2017. There was fog till 10:00 in the morning after which the sky was clear. The data were recorded from 10:30 to 16:00. Ambient temperature varied from 8 ºC to 25 ºC. The air-flow rate was fixed at 5.5 m s-1. The steam started generating at 13:00 and was generated for 3 hours till 16:00.

Variation of temperature of water at low head (L.H.) and high head (H.H.) of the header with solar intensity and time is shown in figure 6. Both temperatures increased with time to a maximum of 75.7 ºC and 101.6 ºC respectively while solar intensity after reaching 827 W m-2 at 12:00 hours, it continuously decreased with time. Figure 7 shows the condition of air at outlet of duct and ambient condition of air in terms of its humidity and temperature. Figure 8 shows the temperature difference obtained for air at the outlet of duct to ambient air, and the humidification rate achived by the setup. The maximum temperature difference obtained was 6 ºC at 14:00 hours then the temperature difference gradually decreased. At 15:30 when the ambient temperature decreased the setup was able to achieve a difference of 4.9 ºC. The maximum humidification rate of 0.580 kg h-1 was achieved at 14:00 hours. The COP of the system calculated for every half an hour is shown in the figure 9. The maximum COP obtained by the system was 0.18 at 14:00 hours.

XI. Conclusions

On a typical north Indian winter conditions where ambient temperature varied from 8 ºC to 25 ºC the setup was able to maintain a temperature difference of 3.5 ºC to 6 ºC for 3 hours. The maximum humidification rate obtained was 0.580 kg h-1. The setup obtained a maximum cop of 0.18. The above results show that the steam generator based on evacuated tube has great potential for replacing winter air conditioners but further research need to be done in this field. Some of the future work that can be done is integrating this system with phase change material or other thermal storage system, automatic controlling of the steam and controlling of air-flow rate with sensors.

XII. FIGURES, EQUATIONS, AND LISTS

A. *Figure 1*

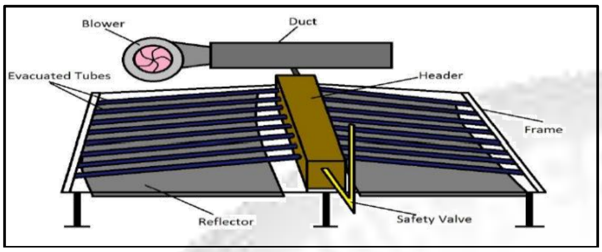

Fig. 1:Schematic Diagram of the Setup

B. *Figure 2*

Fig. 2: Photograph of the Setup

C. *Figure 3*

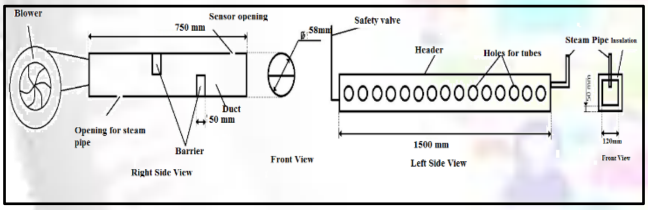

Fig. 3: Schematic Diagram of Duct (Left) and Header (Right)

D. *Figure 4*

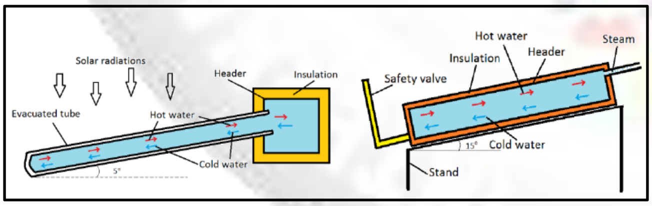

Fig. 4: Thermosyphon in Evacuated Tubes (Left) and Thermosyphon in Header (Right)

E. *Figure 5*

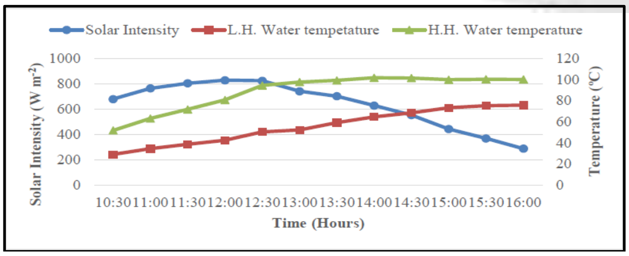

Fig. 5: Variation of Water Temperature and Solar Intensity with Time

F. *Figure 6*

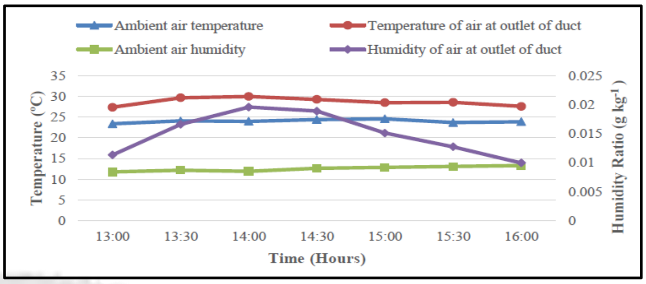

Fig. 6: Variation of Temperature and Humidity Ratio with Time

G. *Figure 7*

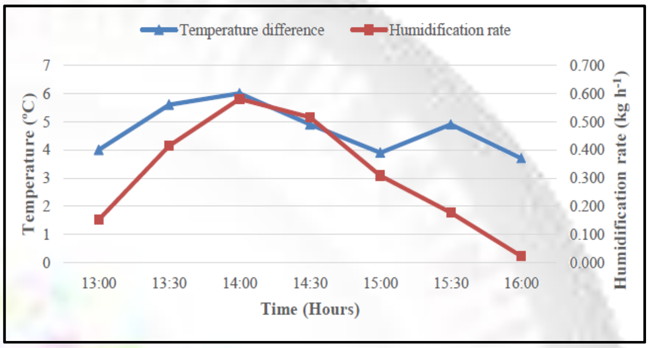

Fig. 7: Variation of Temperature Difference, Humidification Rate with Time

H. *Figure 8*

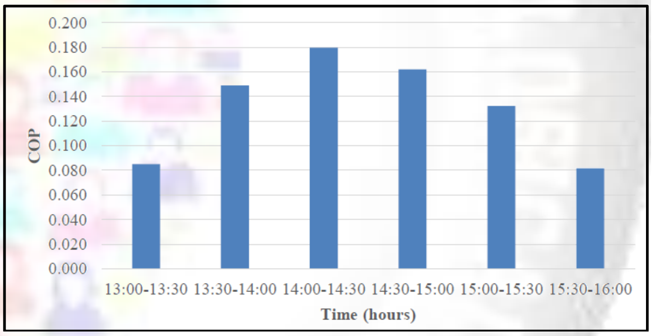

Fig. 8: Variation of System COP with Time

Equations

$$COP=(h2-h1)IAdt \quad \text{(eq. 1)}$$

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