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Design and thermal performance evaluation of a novel solar air heater

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ABSTRACT

In the present scenario, numerous applications perform on solar energy for cooking, heating and cooling, and power generation, globally. Solar air heaters are one of these applications purposely used for, drying, timber seasoning and space heating. In the present work, a solar air heater (SAH) has been designed to produce a good exhaust temperature for long hours especially in the case of poor ambient conditions or during off sunshine hours. A mixture of desert and granular carbon in the ratio of 4:6 has been used as thermal heat storage inside the SAH. Two halogen lights of 300 W are used to increase the exhaust temperature of the SAH by placing them in the inlet and outlet ducts. All the experiments have conducted on natural and forced convection for performance evaluation on two similar design solar air heaters (with and without heat storage). The comparisons are made with two similar design solar air heaters carrying desert and granular carbon, as an individual heat storing media, to find out an optimum design of a SAH with long term heating. The thermal efficiencies of the novel SAH range from 18.04% to 20.78% of natural convection and 52.21%–80.05% with forced convection.

1. Introduction

Solar energy systems can be classified as; solar thermal systems and solar PV systems. In solar thermal systems, the function of a solar collector is the conversion of solar radiation on its surface into energy (in the form of sensible or latent heat in a fluid, which is passed through the collecting unit). Numerous types of solar energy collectors have been devised in recent years [1,2], among which SAH is commonly used device. In the earlier phase, various types of SAHs have been designed and tested for certain rating parameters. These SAHs are used for the purpose of, crop drying, space heating, and for re-generating dehumidifying agents [3]. SAHs offer the possibility of providing cheap, low-grade heat, because of their inherent simplicity.

From the point of view of both materials and configurations, there are many possible designs for SAHs. Selective surfaces, Vee-corrugated and finned absorber plates are beneficial to achieve a good improvement in the performance of a SAH through natural convection [4]. It has also been observed that solar thermal devices perform better by providing a good energy storage material. Quality TES materials increase the heat storing capacity of a solar device for long hours. These energy storage systems include 'designed containers' underground aquifers and 'soils' and 'lakes, bricks and ingots'. In these systems, thermal energy is stored in the form of sensible heat and latent heat [5].

From the engineering and economic point of view, it is important that the designed system should able to supply the energy (round the year) or provide the desired output at the time of requirement. Normally, solar energy systems can perform well for 7–8 h in summer and 4–5 h in winter (at Moradabad, latitude-28°58′N and Longitude-78°47′E), consequently it becomes tougher to perform in the off sunshine hours, bad climatic conditions or in the night. Therefore, the lack of robust heat storage systems for solar energy is considered as an important problem that hampers the development and the promotion of solar energy. The efforts have been made to design such a SAH that can be performed well round the year. The present designs is quite different from previous designs either they are hybrid SAHS or SAHS performs on thermal heat storages (Table 1), individually [35]. The novelty of the system is-its improved design with enhanced η_{therm}. It is the first kind of the SAHS which can perform on auxiliary power along with a higher thermal heat storage in any type of ambient conditions at very low cost (i.e., fabrication cost or operating cost).

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Nomenclature

SAHs	solar air heaters
TES	thermal energy storage
LHS	latent heat storage
SAH	solar air heater
SAHS	solar air heating systems
PCM	phase change material
FPC	flat plate collector
HHTS	high heat thermal storage
ff	friction factor
I	solar radiation (W/m^2)
V	flow speed in m/s
A	flow area in m^2
C_P	specific heat of air (kJ/kg K)
F_R	heat removal factor
A_C	collector surface area (m^2)
k_i	thermal conductivity of insulator (W/m K)
PV/T	photovoltaic thermal
v_w	wind velocity (m/s)
T	temperature (°C)
$\dot{m}$	mass flow rate of fluid (kg/s)
T_b, T_{ps1}	temperature of absorber plate of model s1 (°C)
T_c, T_{ps2}	temperature of absorber plate of model s2 (°C)
T_{bo}, T_{os1}	temperature of exhaust air of model s1 (°C)
T_{co}, T_{os2}	temperature of exhaust air of model s2 (°C)
T_{ci}, T_i	fluid inlet temperature to the collector (°C)
η	efficiency of the collector or system (%)
U_L	overall heat loss coefficient of the collector W/(m^2 °C)
U_b	bottom heat loss coefficient
L	length of the cross sectional area of the duct (m)
H	height of the cross sectional area of the duct (m)
s1	solar air heater without thermal storage
s2	solar air heater with thermal storage
t_i	thickness of the insulator (m)
h_w	heat convection coefficient for air flowing over the glazing (W/m^2 K)

Greek symbols

β	collectors tilt angle (degree)
ρ	density of the fluid in kg/m^3
μ	dynamic viscosity in kg/(s·m)
τ	transmittance
α	absorptance

Subscript

p	temperature of absorber plate (°C)
a, amb	ambient temperature (°C)
1,2,3,4,5,6,7,8,9,10	*different absorbers of FPC*
therm	thermal
elect	electrical
o	outlet

A few references [6–29] show the SAHs perform on TES, while the references [30,31] show the hybrid SAHs perform on solar energy along with auxiliary power. But, none among those designs [6–31] have the quality to be performed on both (i.e., TES and auxiliary power), except the present SAH.

2. Materials and methods

All the experiments have been conducted at Moradabad Institute of Technology, Moradabad. To make a comparison of the present design over the conventional design, two SAHs (s1 and s2) of similar design have been fabricated by easily available material. The authors have been considered the design of the two other models [24,25] and make some effective modifications for the experimental work.

The mixture of the desert sand and granular carbon (in an optimum ratio) was considered as TES material. The model s1 was simply performed on an *Al* made blackened absorber tray, while the model s2 performed on a quality TES material (Fig. 1(a)). For a detail, the plywood of 1 cm thickness was used for the fabrication of both the systems. The specific area of the blackened absorber tray (22 SWG *Al* sheet of 0.5 mm thickness) was approximately 151×53 cm^2. A 2 cm thick layer of glass-wool was placed between the absorber tray and outer cabinet to reduce the heat losses. A, 0.3 cm thick single pane transparent glass of 151×70 cm^2 area was used for glazing to allow the solar energy in the system. The distance between glazing and absorber tray was 10 cm. The side walls of the collector were tilted at 115° angle to receive a good amount of solar radiation through its exposed area (Fig. 1(b)). The single glazing was considered especially for the maintenance of the present SAH. The efficiency effecting elements of SAH such as; halogen lights, inside walls of the ducts (for good reflectivity), and the absorber tray (i.e., a transparent glass covering the TES) are required to be very clean for efficient working in poor ambient conditions. Dusty transparent covers over storage media and dusty reflective walls results in low efficiency of SAH [32]. The system was placed southward at 43° from horizontal because the optimum solar collector orientation is south facing to perform well round the year in the northern hemisphere. It is notable that the optimum tilt depends upon the latitude and the solar inclination and can be estimated by (latitude +15°) [33 and 35].

A table fan (40 W) of Cinni-20 CR™ was used to supply the air inside the SAH. The flow rate of the air was set at 2 m/s. Besides this, a cylindrical tapered shaped vessel was used to connect the fan directly to the inlet duct of SAH to supply the air to the system (in the case of forced convection). This vessel was fabricated from an *Al* made bucket with two open 'ends' in which, the round shaped end was fixed directly with fan, while rectangular end was fixed to the inlet duct of SAH to supply the air. Other two ducts (the inlet and outlet ducts, made of the same grade of *Al*) of the same dimensions were fitted to the SAH to supply the air and for exhaust (element 6 in Fig. 1(a)). The temperature of the air (flowing inside the ducts) was increased while passing through the ducts because a high flux generated through the halogen lamps placed inside the ducts and reflective walls of the ducts.

In the model s2, a thin layer of 1.5 mm of the mixture of desert sand (porosity-26%) and granular carbon was spread over the blackened absorber (i.e., *Al* made absorber tray) along-with side walls and fully covered by a transparent toughened glass of 1.25 mm thickness (Fig. 1(b)). The properties of both the materials are shown in Table 2. The test mixture of desert and carbon was sieved to 20×50 (US Sieve) mesh, yielding a particle size range from 0.30 to 0.89 mm. It is notable that the desert sand and granular carbon have also been tested separately in similar design of SAH and found satisfactory for space heating [24,25] and discussed here to make a comparison with references [24,25], to find out the best SAH design. In the present work, the efforts have been made to improve the heat transfer rate and to enhance