International Journal of Research in Engineering and Innovation (IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

ORIGINAL ARTICLE

Experimental thermal performance evaluations of low cost plastic porous and non-porous absorber collectors for crop drying applications air heating in rural areas

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Article Information

Received: 12 Oct 2024
Revised: 16 Oct 2024
Accepted: 25 Oct 2024
Available online: 29 Oct 2024

Keywords:

Plastic Solar Air Heating Collectors;
Porous and Non Porous Solar Plastic Air -heaters;
Theoretical and Experimental Performances of air heaters

Abstract

This paper presents experimental studies on solar air/water heating systems with integrated storage, utilizing low-cost plastic films, alongside the development of a thermal model. Explicit expressions for air and absorber temperatures were derived, and the model's utility was validated through experiments conducted over several days on various systems. A close agreement between theoretical predictions and experimental results confirmed the accuracy and reliability of the proposed methodology. The findings demonstrated the effectiveness of these solar air heaters for crop drying applications in rural areas, highlighting their potential as a cost-effective and sustainable solution for agricultural needs. This study underscores the feasibility of using low-cost materials in solar heating systems, promoting energy-efficient and accessible technologies.

1. Introduction

Energy is a critical input in the national development process. In fact, it is the basic requirement for human life, agriculture, industry, transportation, communication, and many other economic activities of the present civilization. In the present day, with the depletion of fossil fuels in various countries, the terms of energy crises underline the need to pay serious attention to the effective /efficient utilization of existing conventional and nonconventional energy sources in terms of energy conservation through effective management for maximum agricultural production. The thermal performance of solar air heaters consisting of a porous textile absorber between two PVC foils has been investigated. The efficiency of the heaters depends strongly on the characteristics of the textile forming the absorber and the back insulation. For an incident solar radiation of 687 W/m2 at the collector's surface, a temperature rise of 16-6°C in the air flowing through the solar collector at a rate of 800 m3/h with a thermal efficiency of more than 70 % was observed [1]. Similarly, the thermal performance of solar air heaters consisting of a porous textile absorber between two PVC foils has been investigated and found that the linear approximation for the Hottel-Bliss equation for the collector's parameters when the absorber is porous and compared with nonporous absorber solar air heating collector and it was found that the efficiency of the heaters depends strongly on the characteristics of the textile forming the absorber [2]. The thermal performance of a flat-type honeycomb porous bed solar air heater in which air flows perpendicularly from the transparent cover to a porous absorber plate with a mass flow rate of m > 40 kg/m2h has been evaluated and found the best operating efficiency obtained when running the collector thermal performance is superior to channel type solar air

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https://doi.org/10.36037/IJREI.2024.8501

heaters operating under similar conditions [3]. The problem inhibiting the popular use of solar water heating systems is the cost of the delivered useful energy, which has to be estimated using proper techno-economics. The numerical calculations are made for Indian market conditions and Delhi (India) climate for open-loop water heating systems and closed-loop water heating systems, with a heat exchanger in the collector loop. The basic problem that deserves to be considered for all types of solar water heating systems is the optimization of the collector with respect to the cost of useful delivered energy for various storage capacities. It was observed from computation that the cost of solar energy comes out to be more than that of electrical energy, which has been highly subsidized in alternative systems. The cost of useful delivered energy comes out around the cost of electrical energy without a subsidy and 10% less with a subsidy. The optimized collector area for 70°C desired temperature for 200 liters of daily hot water demand comes out to be 2.5 m2 for 180 liters of tank capacity and 2 m2 with a heat exchanger in the collector loop.

The cost of the useful delivered energy will be higher if an auxiliary heating system is provided inside the storage tank instead of at load. For a forced flow system, the cost of the delivered useful energy comes out 15% higher [4].

The accurate TRNSYS simulation program can be used in simulating different configurations of forced circulation solar water heating systems and inspecting the most prominent parameters that affect the discrepancy between simulation and experiment, which showed the discrepancy in the position of the temperature sensors controlling the circulation of the pump [5]. Expressions for the performance parameters F', U_L, and F_R of various collector configurations consisting of an air-heating collector connected to a compact air/water heat exchanger, but these performance parameter derivations have not been documented. The derivation of performance parameters is accomplished for an air/water heating system by considering duct losses in the solar water heating systems have been carried out. The utility of these performance parameters in finding the rating parameters of an air/water heating system and mutual comparisons of various of these parameters for other systems were also investigated [5]. A dimensionless analysis of matrix air heaters has been developed to study the effect of different boundary conditions on their performance. The authors compared theoretical results with measurements of an experiment performed with a matrix solar air heater and found the fourth set of boundary conditions; the theoretical results agree fairly well with experimental data and compared with other suitable boundary conditions. For this particular set of boundary conditions, the thermal performance of the system has been compared for different mass flow rates of air and as a function of other physical parameters and found that 10 to 15% higher thermal performances than using nonporous solar air heating collectors depending on the particular designs [6]. A simple solar air heater made from cheap plastic wrapping film with air bubbles for use in drying operations on a farm (grain, fruit, fish, etc.) was developed by the investigator, and the Theoretical model used was a single-sheet cylindrical collector and, after it had gained some heat, another layer of the plastic wrapping film with air bubbles was added in a later stage to decrease convection heat losses to the surroundings. Each cylindrical collector was 5m long and 0.36 m in diameter, with a black interior band covering the lower part of the collector (30% of the surface area). The inlet direction of the collector was always towards the wind in order to achieve maximum airflow inside the collector and a considerable gain in the temperature of the airflow, a temperature difference of around 10°C. A theoretical and experimental study, including the combined convective and radiative heat transfer analysis of a flexible cylindrical type solar air-heater for circular and two elliptic shapes with 0.55 and 0.65 m major axis, are presented. The solar collector is manufactured from films acting as a black absorber with back insulation and double transparent covers sealed together along its edges. The collector is to be blown with a flow of pressurized air. A computer program is written for calculating the outlet temperature and collector thermal efficiency. Moreover, the Nusselt number between the absorber and the heated air is determined experimentally in relation to the Reynolds number. Comparisons between the experimental data and the theoretical methods for the collector efficiency demonstrate a good agreement. In addition to this, the present experimental results of the Nusselt number are correlated and compared [8].

2. Results and Discussion

Solar air heating has paved the way for the development of water heating systems utilizing porous and nonporous plastic absorber collectors. These systems operate using air-to-water heat exchangers within closed-loop cycles, enhancing energy efficiency. The thermal performance of two solar air heaters, each incorporating a porous absorber, has been systematically analyzed. The findings reveal that the thermal efficiency of these plastic air heaters is significantly influenced by the characteristics of the porous textile absorber and the type of back insulation employed. Key factors affecting performance include the thickness of the textile absorber and the thermal properties of the three types of back insulation used. These variations are detailed in Table-2(a) through Table-2(c). The study underscores that the absorber's thickness plays a crucial role in determining the heat transfer efficiency, as it directly affects the air heater's ability to absorb and retain solar energy. Moreover, the choice of back insulation further influences overall thermal efficiency by reducing heat losses. The use of porous materials in these systems demonstrates their effectiveness in capturing and transferring heat to the air, which is subsequently used in the heat exchanger for water heating. The interplay between the absorber's material properties and the insulation type highlights the importance of material optimization in designing efficient solar air heaters. hese insights contribute to the advancement of sustainable energy technologies, emphasizing the need for innovative material design and system configuration.

Table-1: Specifications & Dimensions of low-cost plastic collectors for air and water heating systems

S. No.	Dimensions/parameters	Porous Absorber	Non-Porous Absorber	PVC Absorber
1	Length of Solar Collector	10.0 m	9.15 m	9.10 m
2	Width of Solar Collector	1.0 m	0.92 m	1.10 m
3	Absorber Area	10 m^2	9.02 m^2	10.01 m^2
4	Material of cover	PVC (Transparent)	Fluoro- polymer	PVC
5	Thickness of top cover	0.7mm	0.6mm	0.6mm
6	Transmittance of the top PVC cover in the solar sprectrum range	0.90	0.94	0.83
7	Thickness of inside cover	0.60 mm	0.30 mm	0.30 mm
8	Material of the cover	PVC Black	PVC Black	PVC Black
9	Transmittance of the inside cover in the solar sprectrum range	0.90	0.94	0.83
10	Material of Porous Absorber	Black porous textile cloth	Black PVC	Black PVC
11	Thickness of Absorber	1.8 mm	0.6mm	0.6mm
12	Material of tubes of Air/water Heat exchanger	Copper	Copper	Copper
13	Diameter of tubes of heat exchanger	12.5 mm	12.5 mm	12.5 mm
14	Materials of Fins of the heat exchanger	Copper	Copper	Copper
15	Wattage of motor of blower	480 W	480 W	480 W

Table-2(a): Thermal performance of textile absorber plastic film solar air heating collectors (for area of absorber= 10 m^2), Ground nut shell insulation

Insulation	Flow Rate (m^3/hr)	Solar Radiation (W/m^2)	Temp Difference (°C)	Thermal Efficiency of collector
Ground nut shell	0.00722	765	25.8	0.2440
Ground nut shell	0.01214	770	17.1	0.2710
Ground nut shell	0.01464	770	16.3	0.3115

Table-2(b): Thermal performance of textile absorber plastic film solar air heating collectors (for area of absorber= 10 m^2), with wood filling as insulation

Insulation	Flow Rate (m^3/hr)	Solar Radiation (W/m^2)	Temperature Difference (°C)	Thermal Efficiency of collector
Wood filling	0.00722	800	27.3	0.2470
Wood filling	0.01556	795	16.3	0.3206
Wood filling	0.01695	790	15.7	0.3385

Table-2(c): Thermal performance of textile absorber plastic film solar air heating collectors (for area of absorber= 10 m^2), with 25 mm thick thermocol as insulation

Insulation	Flow Rate (m^3/hr)	Solar Radiation (W/m^2)	Temperature Difference (°C)	Thermal Efficiency of collector
25mm Thermocol	0.00722	755	22.8	0.2191
25mm Thermocol	0.01453	790	18.9	0.3494
25mm Thermocol	0.01806	810	17.9	0.4011

A transient thermal model was developed to evaluate the thermal performance of solar water heating systems that employ low-cost porous absorber plastic collectors. These systems incorporate air-to-water heat exchangers operating in a closed-loop cycle. The theoretical predictions generated by the model were compared with experimental measurements conducted in open-loop cycles, with results presented in Table-3. The comparison between theoretical and experimental data revealed a strong correlation, with only slight deviations noted. These minor variations are primarily attributed to nonlinear and random fluctuations in ambient temperature and solar radiation, which can impact system performance. Despite these variations, the model demonstrated high reliability in predicting the dynamic thermal behavior of the system. The transient thermal model simulates critical heat transfer processes and energy interactions occurring within the porous absorber collectors and the heat exchangers. It accounts for the influence of environmental parameters, material properties, and operational conditions, making it a robust tool for analyzing and optimizing system performance. The study highlights the potential of using low-cost porous absorber plastic collectors in solar water heating applications. The close agreement between theoretical predictions and experimental data underscores the model's accuracy and its applicability in practical scenarios. By identifying the impact of external factors, such as ambient temperature and solar radiation, the model provides valuable insights into improving the design and efficiency of these systems. The findings demonstrate that low-cost, porous absorber plastic collectors, coupled with air-to-water heat exchangers, offer a viable solution for sustainable energy generation. The developed thermal model serves as a critical tool for advancing the design and operational strategies of solar thermal systems. It ensures efficient energy utilization and reduces dependency on conventional energy sources.

Table-3: Performance of open loop plastic porous air heating solar collectors using with air/water heat exchanger (Ac= 10m^2)

Time	Inlet temperature (°C)	Isolation (W/m^2)	Theoretical Water temperature difference (°C)	Experimental Water temperature difference (°C)	Theoretical air temperature difference (°C)	Experimental air temperature difference (°C)	Thermal Efficiency (%)
10.0	20.0	545	6.8	6.0	6.7	6.0	39.8
10.15	20.1	610	7.1	7.5	7.1	6.1	40.6
10.3	21.2	673	7.5	8.5	7.5	6.9	40.28
10.45	22.3	707	8.3	7.2	8.3	7.4	41.07
11.0	24.2	737	8.1	9.9	8.1	7.9	38.2
11.15	25.7	523	9.0	8.9	6.0	5.8	40.15
11.30	26.8	457	7.9	7.8	5.0	4.6	41.0
11.45	27.8	284	5.7	5.6	3.3	3.2	41.3
12.0	28.0	349	5.6	5.7	3.1	2.9	41.6
12.15	28.5	450	6.9	6.7	4.1	3.9	39.9
12.30	28.7	960	9.4	9.0	9.9	9.8	36.2
12.45	29.2	800	9.3	10.2	8.2	8.25	36.0
13.0	29.6	825	7.1	6.9	9.2	9.8	38.9
13.15	29.4	839	6.5	6.0	9.5	11.2	39.6
13.30	29.8	817	6.2	5.5	9.2	9.6	39.5
13.45	30.0	885	6.0	5.9	9.5	10.5	39.27
14.0	29.8	788	5.8	5.7	9.9	10.1	40.16
14.15	29.6	885	6.0	5.9	9.5	10.5	39.27
14.30	29.8	788	5.8	5.7	9.9	10.1	40.16
14.45	29.6	885	6.1	6.0	9.9	10.2	30.7
15.0	29.4	575	6.1	6.0	9.9	11.2	45.2
15.15	29.2	475	6.5	5.3	6.5	6.7	48.0
15.30	29.1	454	5.8	6.2	4.85	4.9	45.1

3. Conclusions

In this paper, the Transient thermal model was developed to validate experimental measurements with theoretically calculated results obtained from the mode. It was found that results obtained from this model matched with experimentally measured values. The performances of nonporous absorber solar plastic air heating collectors have also been presented using rural insulations, and it was found that these solar air heaters work well in rural areas for crop drying applications.

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Cite this article as: Radhey Shyam Mishra, Experimental thermal performance evaluations of low-cost plastic porous and non-porous absorber collectors for crop drying applications air heating in rural areas, International Journal of Research in Engineering and Innovation Vol-8, Issue-5 (2024), 167-170. *https://doi.org/10.36037/IJREI.2024.8501*.