ABSTRACT

In this paper, an attempt has been made to review various designing and performance testing methods for solar thermal systems. The review has also covered various solar thermal applications. The objective is to highlight designing and testing methods so as to optimize the solar heater design. Various technologies that improve performance in different solar thermal applications like, cooking, distillation, drying have been analyzed. The identified technologies drawn from review are modified internal geometry, reflecting mirror, optimizing absorber plate roughness, and use of thermal storage material. Some performance testing methods have also been reviewed. The literature review is followed by a discussion in which, it has been proposed to integrate these technologies in a solar thermal system for attaining most optimum performance. It was also proposed to apply reviewed testing methods in optimization process for the analysis of identified techniques.

KEYWORDS Solar heater, thermal efficiency, drying rate, indoor testing, interferometry, temperature-rise.

1. INTRODUCTION

The solar energy is absorbed and converted into useful energy by two means viz. solar thermal technology and photovoltaic technology. In this paper, solar heating has been selected for analysis. Solar heating is found in food drying, water heating, building heating, and in various agricultural applications. Various solar thermal technologies and designs have been studied and analyzed in the context of optimizing the performance of solar heater. The design parameters for solar collector with improved technologies have been discussed along with analysis of the impact of integration of various technologies applied to enhance the performance of solar heater. Modeling and simulation investigations carried out for predicting the performance of solar dryer and functioning of solar dryer with various applications is also presented. Finally, a discussion is made for performance evaluation and scope of further investigation and improvement.

2. LITERATURE REVIEW

2.1 Analysis of collector design

Naveen Kumar et al [1] designed a truncated pyramid-type solar cooker as described in figure 1, which has features to reduce cooking times and is low on cost. This study aims to report the design; fabrication and testing of concept of truncated pyramid geometry for developing a solar dryer cum cooker suitable for household applications.

![Figure 1. Experimental setup of truncated pyramid solar cooker](image)

The concept of concentrating solar energy was utilized to achieve high temperatures and to trap the collected energy for retaining high temperatures over a considerable period of time. Combining these two advantages into a single design resulted in a new truncated pyramid–shaped solar cooker with enhanced performances. Highest absorbing stagnation plate temperature reached was 112°C with tilted base and 119°F with horizontal base.

2.2 Impact of integrating technologies

Riyad Hodali and Jacques Bougard [2] have integrated a desiccant unit in crop solar drying. The set up for the experiments is a direct flat plate forced convective solar dryer. The drying unit is integrated with silica gel as desiccant. The authors investigated the daily absorption cycle of desiccant with the application of numerical simulation to drying of apricots in Morocco under real climatic conditions. The quality of dried food was improved and drying period was reduced from 52 hrs to 44 hrs.

Shanmugam V. and Natarajan E. [3] have performed an experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror. The set up for their work is an indirect forced convection with desiccant integrated solar dryer. They observed the operation in sunshine and off sunshine hours. The regenerative desiccant bed was used to run the system in off sunshine hours. The effect of reflective mirror was also investigated and with that the drying potential of the desiccant unit was increased by 20% and the drying period time was also reduced. The drying efficiency of the system varies between 43% and 55%. The inclusion of reflective mirror on the desiccant bed makes faster regeneration of the desiccant material.

P. A. Potdukhe and S. B. Thombre [4] developed and tested a new type of solar dryer fitted with a novel design of absorber having inbuilt thermal storage capabilities at RGCERT Chandrapur, (Maharashtra), India. The main objective of the study was to reduce the drying period and enhance the quality of dried products namely chillies and fenugreek leaves. The use of thermic oil was introduced in absorber. The research concluded that the desired drying air temperature i.e. 65°C was achieved and maintained for long period.

A. A. El-Sebaii et al [5] have performed an experimental investigation of an indirect type natural convection solar dryer. The concerned experimental set up was a flat plate solar air heater connected to a drying chamber. The air heater was integrated with a storage material (sand) under absorber. Observations were made on the operation of the system with and without storage material for different spherical fruits. The observation was based on solar irradiance,
temperature distribution in different parts of the system, ambient temperature and RH of the inlet and outlet air. The drying period was reduced by 12 hours with the use of storage system.

T.V. Arjunan et al [6] have performed an experimental study on the effect of the different energy storage materials in solar still. Two identical solar still units were fabricated with the effective area of 0.5 sq. metre in order to investigate the effect of different materials such as black granite, pebbles, blue metal stones were used as sensible heat storage. Paraffin wax was also used as latent heat storage. A fixed mirror on the inner wall surfaces was used to reflect the radiations into the basin water. The highest temperature of 81.5°C was obtained at the inner wall surface. The experimental result has shown that, among the sensible heat storage materials black granite has given better output than others for 24 hours period and paraffin were given more productivity during the night time. It has also been observed that, combination of reflector and storage materials improved the productivity considerably (Figure 2).

Vishvajeet Singh Hans et al [7] have investigated heat transfer and friction characteristics of a multiple V-rib roughness solar air heater. The flow system was consisted of an entry section, a test section, an exit section, a flow meter and a centrifugal blower. In this experimental investigation, multiple V-ribs with apex facing downstream have been used to create artificial roughness. In order to investigate the effect of multiple V –ribs on heat transfer enhancement and friction factor, relative roughness ( W/w) parameter was considered and defined as, W/w = Width of absorber plate/ width of single V-rib. Maximum heat transfer enhancement over single V-rib was obtained for width ratio value of 6 (Figure 3).

2.3 Modeling, Testing and visualization of drying/heating process

Dilip Jain [8] has presented a transient analytical model to study the new concept of a solar crop dryer having reversed absorber plate type collector and thermal storage with natural flow. The set up consists of 1x1 sq.m crop dryer with packed bed, two trays viz. tray I and tray II and airflow channel for drying of onions. The developed model was solved to compute the air temperature and various functional components of the drying systems for the climatic condition of Delhi (India). The parametric study involved the effect of width of airflow channel and height of packed bed on the crop temperature. A reversed absorber plate of 1m length with 0.15 m packed bed could dry 95 kg. of onions from a moisture content of 6.14 to 0.27 kg water/kg of dry matter in a 24 h drying period.

F.K. Forson et al [9] have done the mathematical modeling of a single pass, double duct solar air heater. The developed model can predict incident radiation, heat transfer coefficient, mean air temperature and RH at the exit. The results were compared with experimental ones, and a reasonable agreement was found between the predicted and measured values.

S Janjai et al [10] simulated the performance of the roof-integrated solar dryer for drying herbs and spices using hot air from roof-integrated solar collectors. Two sets of equations were developed, first set of equations was solved implicitly and the second set of equations was solved explicitly using finite difference technique. A good agreement was also found between experimental and simulated moisture contents.

F. Almeida et al [11] conducted an experimental study to examine free convection in a window with an enclosed aluminum Venetian blind. The unique feature of this experiment was that the blind slats were heated electrically to simulate absorbed solar radiation. Centre-glass convective heat transfer measurements and temperature field visualization were obtained using a laser Mach-Zehnder interferometer (Figure 4).
differences (T_{H}-T_{C}) (0°C and 15°C). It was found that a recently proposed simplified model, called the Reduced Slat Length (RSL) model, closely predicted the experimental results when the flow appeared to be laminar and steady.

Figure 5. Indoor experimental set up of PV/T air collector.

C. Solanki et al [12] conducted indoor simulation and testing of photovoltaic (PV/T) air collectors. An indoor standard test procedure has been developed for thermal and electrical testing of PV/T collectors connected in series as shown in figure 5. For this, a PV/T solar air heater has been designed, fabricated and its performance over different operating parameters were studied. Based on the energy balance equations, in a steady state condition, a thermal model has been developed. Comparison between experimental and theoretical results were also been carried out. The thermal and electrical efficiency of the solar heater is 42% and 8.4%, respectively. The experiments were carried out in indoor condition and parameters were measured by varying the mass flow rate of air and solar intensity. PV/T air collectors are tested under solar simulator which has 16 tungsten halogen lamps each having 500W and rated at 240 V and 11A. The results obtained in indoor simulation are similar to the results obtained by previous researchers for outdoor conditions.

S.V. Karmare et al [13] used CFD technique in the analysis of fluid flow and heat transfer in a rib roughened surface solar air heater. Lower side of collector plate is made rough with metal ribs of circular, square and triangular cross-section, having 60° inclination to the air flow. And, it is found that experimental and CFD analysis results give the good agreement. The optimization of rib geometry and its angle of attack is also done. The square cross-section ribs with 58° angle of attack give maximum heat transfer. The percentage enhancement in the heat transfer for square plate over smooth surface is 30%. The schematic layout of experimental setup is shown in figure 6. ASHRAE standards (1977) were followed while fabricating the set up.

Figure 6. Experimental set up (S.V. Karmare et al).

Stefan Goppert et al [14] investigated the effects of thermal stratification in reducing sucking effects in solar storage tank. They attempted to visualize flow patterns during sucking effect using optical technology (Figure 7).

The efficiency of low-flow solar systems is strongly influenced by the quality of the thermal stratification in the storage tank. The better a thermal stratification can be generated and maintained, the higher can be the yield of the solar system. Fluid mechanical charge systems are often used for this purpose, which cause, however, undesirable sucking effects. Therefore, the knowledge of the appearing fluid flows as well as the knowledge of the consequences of constructive changes is very important for the design of such charge systems. Constructive modification in charging pipes has been applied and tested for enhancing thermal stratification and in turn reducing sucking effects.

Dilip R. Pangavhane et al [15] developed and tested a new natural convection solar dryer consisting of a solar air heater and a drying chamber. This system can be used for drying various agricultural products like fruits and vegetables. A natural convection solar dryer was manufactured and installed at the School of Energy and Environmental Studies, Devi Ahilya Vishwa Vidhyalaya, Indore (India). It consists of a solar flat plate air heater, flexible connector, reducer-cum-plenum chamber with chimney and a supporting stand. The solar air heater consists of an absorber (painted matte black) with fins, glass cover, insulation and frame. The air duct beneath the absorber was made from an aluminium sheet through which air was passed. The U-shaped corrugations (11 in number) were placed in the absorber plate parallel to the direction of airflow. In the drying experiments, Thompson seedless grapes were used as the test samples in the dryer. Drying experiments were performed during the period March–May. The developed natural convection solar dryer is capable of producing the average temperature between 50°C and 55°C, which was optimum for dehydration of the grapes as well as for most of the fruits and vegetables. The drying time of the grapes is also reduced by 43% compared to the open sun drying.

Turhan Koyuncu [16] constructed and analyzed six different types of natural circulation air heating solar collectors (Model-1: single plastic glazing, black painted hardboard absorber and front-pass; Model-2: single plastic glazing, black painted flat plate absorber and front-pass; Model-3: single plastic glazing, black painted zigzag plate absorber and front-pass; Model-4: single plastic glazing, black painted flat plate absorber and back-pass; Model-5: single plastic glazing, black painted zigzag plate absorber and back-pass; Model-6: double plastic glazing, black painted flat plate absorber and back-pass for their performance in this study (Figure 8).
efficiency for the double pass mode is most significant in the flat plate collector and least in the V-groove collector.

2.4. Solar heater applications
B. A. Ezekoye and O.M. Enebe [18] have developed a passive solar grain dryer for drying grains with the advantage of low temperature drying that enabled crops to be dried without cracking and hence minimized the exposure of crops to fungal and bacterial infestation. The dryer achieved a moderate temperature of 60.0°C, which is needful for passive solar grain dryers. The drying efficiency was found as 22%.

M. A. Hossain and B.K. Bala [19] tested a mixed mode type forced convection solar tunnel dryer for drying red and green chilli. The drier consisted of transparent plastic covered flat-plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel. The dryer had a loading capacity of 80 kg of fresh chillies. Moisture content of red chilli was reduced from 2.85 to 0.05 kg/kg (dry basis) in 20 hours. In case of green chilli, about 0.06 kg/kg (dry basis) moisture content was obtained from initial moisture content of 7.6 kg/kg (dry basis) in 22 h.

M. A. Karim et al [17] studied the performances of three types of solar air collectors, namely flat plate, finned and V-corrugated, has been performed towards achieving an efficient design of air collector suitable for a solar dryer. A series of experiments were conducted, based on the ASHRAE standard, under Singapore climatic conditions. The performance of all three collectors is examined over a wide range of operating and design conditions. The V-corrugated collector is found to be the most efficient collector and the flat plate collector the least efficient. The collectors are also studied in double pass mode to investigate the extent of improvement in efficiency that can be achieved without increasing the collector size or cost. The improvement in efficiency for the double pass mode is most significant in the flat plate collector and least in the V-groove collector.

Hanaa M. Fargali et al [20] proposed and developed a new controlled drying method, which uses a solar collector and a bio gas fuel to heat the drying air for drying medicinal herb. The designed control technique ensured correct and continuous operation of the dryer’s subsystems. The results indicated the high effectiveness of the drying method.

M. Mohanraj and P. Chandrasekar [21] designed, fabricated and tested a forced convection solar dryer for the drying copra under Indian climatic conditions. The moisture content of copra was reduced from about 51.8% to 7.8% and 9.7% in 82 h for trays at the bottom and top, respectively.

M.O. Abdullah et al [22] designed, constructed and experimentally tested a solar attire dryer. The result shows that solar dryer supplemented with forced-ventilation has higher drying rate of 0.43 kg/h and shorter completion drying time of 3 hours compared to solar dryer with natural ventilation which has a drying rate of 0.25 kg/h and drying time of more than 4 hours for a typical day. The solar attire dryer developed in this study by the authors is made from aluminum rod, transparent acrylic plastic sheet, PVC pipe, solar-powered panel with charge controller and ventilation fans.

Fig. 9(a) and (b) are the schematic diagrams showing the front view and side view of the solar attire dryer together with the components and the dimensions.
The total capacity of the dryer is about 15 clothes. All the surfaces of the enclosure are transparent to maximize the quantity of sunlight absorption and to permit the visual inspection of the clothes. The hand-squeezed clothes were successfully dried in the attire dryer within 3 hours, compared to about 5 to 7 hours needed for the conventional cloth lines drying under local conditions.

3. DISCUSSION

Review of previous works outlines different performance enhancement techniques. The internal geometry optimization has impact over thermal performance of solar cooking which is one of the applications of solar air heater. Desiccant material increased drying rate and inclusion of thermal storage material elongated service period makes solar thermal system able to work even in night hours. Addition of reflecting mirrors enhanced thermal performance. Creation of artificial roughness on absorber plate maximized heat transfer rate by inducing turbulence. Various modeling and testing methods have also been reviewed. Laser interferometry was used for examining free convection in solar window and has given useful results. Indoor testing and simulation of solar air heater has given similar results as obtained in outdoor testing. Flow visualization, CFD analysis and experiment results have given a good agreement. Mathematical models were found satisfactory in predicting the results. Forced convection in solar heating applications has given better results. Different solar air heater designs were tested to find optimum design. The suggested thermal storage materials should be tested to identify most suitable and effective one. Investigations are required to obtain most optimum absorber plate roughness. Optimization of internal geometry is also to be studied critically. Indoor simulation and testing method and laser technique are proposed to be applied in optimization. It may enable investigators to test a solar thermal system at constant heat flux irrespective of ambient conditions and give a critical analysis. Flow visualization, CFD analysis and modeling are also proposed to be applied in optimizing the performance. Inclusion of forced convection should also be considered.

The plan of action to be taken for optimization of solar thermal system is as follows;

- Evaluation of geometrical optimization parameters, circulation systems using various critical testing methods, and
- Integration of various technologies.

REFERENCES