

Solar Devices:- Solar Water Heater, Solar Still, Solar Cooker and Solar Dryer: A Review

Aditya P. Todmal¹, Ayush D. Mali², Sarang D. Kale³, Ganesh V. More⁴, Vikrant P. Katekar⁵

^{1,2,3}BE Student, Mechanical Engineering Department, Pune Vidyarthi Griha's College of Engineering and Technology and G.K. Pate (Wani) Institute of Management, Pune 09, Maharashtra, India

⁴ Prof. Mechanical Engineering Department, PVG'S COET & GKPIOM, Pune 09, Maharashtra, India

⁵ Research Scholar, Centre for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Powai, Mumbai, Maharashtra, India

Abstract – In this study the attempt has been made to review the different papers and the solar devices that have been improved over the period of time. Different types of the solar water heater, solar stills, solar cooker and solar dryer have been studied. By examining the existing literature, identifying knowledge gaps, and synthesizing the findings, this review paper aims to contribute to the development and optimization of integrated solar devices. Each device is discussed in detail, highlighting the underlying principles, design considerations, technological advancements, and notable applications. The conclusions drawn from this review provide insights into the feasibility, efficiency, and potential future directions of solar devices.

Key Words: Solar Water Heater, Solar Still, Solar Cooker, Solar Dryer, Distillation, Cooking, Drying, renewable energy, sustainability

1.INTRODUCTION

Researchers were encouraged to use heat recovery systems or renewable energy sources as practical solutions by the ongoing escalation of environmental issues and the ongoing rise in the expense of traditional energy sources. Systems for recovering heat from specific applications are referred to as heat recovery systems [1–11], and this practise increases the effectiveness of the use of energy. On the other hand, geothermal, wind, biomass, and solar energy constitute a majority of renewable energy sources. Solar energy is a unique form of renewable energy source that may be used for a variety of purposes.

The utilization of solar energy as a sustainable and renewable resource has gained significant attention in recent years. Solar devices, such as solar water heaters, solar distillers, solar cookers, and solar dryers, play a crucial role in harnessing solar energy for various practical applications. These devices offer environmentally friendly alternatives to conventional energy-intensive technologies, addressing critical challenges such as water heating, water purification, cooking, and drying.

Solar water heaters are designed to convert solar energy into heat energy, providing hot water for domestic, commercial, and industrial purposes. They have evolved significantly, incorporating advancements in solar collector design, heat storage, and hybridization with other energy sources. These advancements have led to improved efficiency, increased reliability, and integration capabilities, making solar water heaters an attractive option for reducing energy consumption and greenhouse gas emissions associated with conventional water heating systems.

Solar distillers, on the other hand, utilize solar energy to purify water by evaporation and condensation processes. They offer a sustainable solution for addressing water scarcity and providing safe drinking water in regions with limited access to clean water sources. Advancements in solar distillers focus on enhancing energy absorption, optimizing distillation processes, and incorporating innovative materials and control systems. These advancements aim to improve water production rates, energy efficiency, and the overall viability of solar distillation as a cost-effective water purification method.

Solar cookers leverage solar energy for cooking and food preparation, offering an eco-friendly alternative to traditional cooking methods that rely on fossil fuels. Advancements in solar cooker design, including concentrating solar cookers and innovative heat storage systems, have enabled faster cooking times, improved temperature control, and enhanced cooking performance. Integration with intelligent control and monitoring systems allows for precise cooking control and ensures efficient energy utilization, promoting the adoption of solar cookers as sustainable cooking solutions.

Solar dryers utilize solar energy to remove moisture from various agricultural products, herbs, fruits, and other materials. They offer a cost-effective and environmentally friendly alternative to conventional drying methods that rely on fossil fuels or electricity. Advancements in solar dryer design, heat distribution, and control systems have contributed to improved drying efficiency, reduced drying times, and enhanced product quality. Integration with advanced materials and monitoring systems further

optimizes energy utilization and ensures precise control over drying parameters.

This review paper aims to provide a comprehensive assessment of the advancements in solar devices, including solar water heaters, solar distillers, solar cookers, and solar dryers. By analyzing the latest research and developments in these areas, the paper intends to highlight the potential and limitations of these technologies and provide valuable insights into their practical implementation, efficiency optimization, and future directions for research and application. Understanding the advancements and challenges in solar devices is crucial for promoting sustainable energy practices and addressing pressing global issues related to water scarcity, energy consumption, and environmental sustainability.

2. SOLAR WATER HEATER

A solar heater is a device that uses the sun's energy to heat water and generate steam for both household and commercial uses. They consist of solar collectors that absorb solar radiation and convert it into heat energy, which is transferred to a heat transfer fluid or directly to the water. The heated water is stored in an insulated tank for later use. With advancements in technology, solar water heaters offer a sustainable solution for meeting hot water needs in various settings, reducing energy consumption, and contributing to a cleaner and more sustainable future.



Fig -1: Process of heating water using solar energy.

The solar water heater has different types according to the type of circuit and type of heating component used for heating application. They are according to the following:

- Active Solar Water Heater:
- Passive Solar Water Heater
- Flat Plate Solar Collector
- Evacuated Tube Solar Collector
- Batch Solar Water Heater
- Hybrid Solar Water Heater

2.1 Active Solar Water Heater:

Active solar water heaters utilize mechanical or electrical components to circulate the heat transfer fluid through the system. There are two main types of active solar water

heaters: direct circulation systems and indirect circulation systems. In direct circulation systems, the water to be heated circulates directly through the solar collector and into the storage tank. In indirect circulation systems, a separate loop of heat transfer fluid circulates through the collector and transfers the heat to the water through a heat exchanger.

2.2 Passive Solar Water Heater

Passive solar water heaters rely on natural convection and gravity to circulate the heat transfer fluid without the need for mechanical or electrical components. There are two common types of passive solar water heaters: integral collector-storage (ICS) systems and thermosiphon systems. ICS systems consist of a storage tank located within an insulated box or collector. Water flows through tubes or channels within the collector, absorbing heat and transferring it to the storage tank. Thermosiphon systems have the storage tank positioned above the collector. As the heat transfer fluid heats up, it rises naturally, creating a thermosiphon effect that circulates the fluid between the collector and storage tank.

2.3 Flat Plate Solar Collector

Flat plate collectors are the most common type of solar collectors used in solar water heaters. They consist of a dark-colored, flat plate with a transparent cover and fluid passages. Sunlight is absorbed by the plate, heating the fluid flowing through the passages. Flat plate collectors are suitable for moderate temperature applications and regions with mild climates.

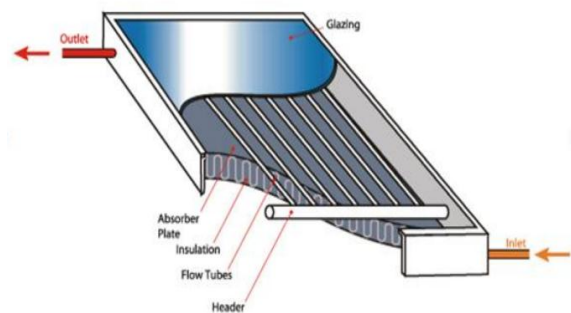


Fig -2: Flat Plate Collector

2.4 Evacuated Tube Solar Collector

Evacuated tube collectors are a more advanced type of solar collector that offers higher efficiency and better performance in colder climates. They consist of parallel glass tubes with an absorber plate inside each tube. The tubes are vacuum-sealed, reducing heat losses and improving heat absorption. Each tube operates independently, allowing for better heat absorption even when some tubes are shaded or damaged.

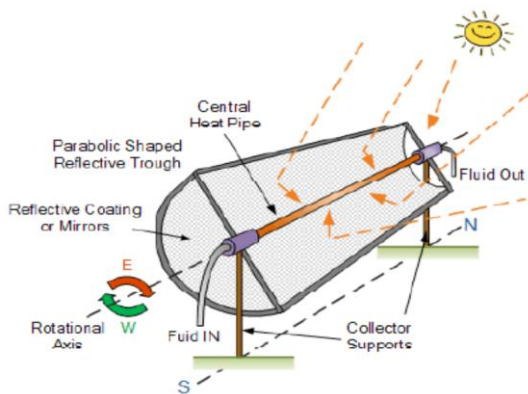


Fig -3: Evacuated Tube Collector

2.5 Batch Solar Collector

Batch solar water heaters, also known as batch or integrated collector-storage (ICS) systems, combine the functions of the solar collector and storage tank into a single unit. The entire unit is usually insulated and covered with a transparent material. Water is directly heated in the storage tank as it flows through the collector portion of the unit. Batch solar water heaters are simple and cost-effective, suitable for low-demand applications and regions with ample sunlight.

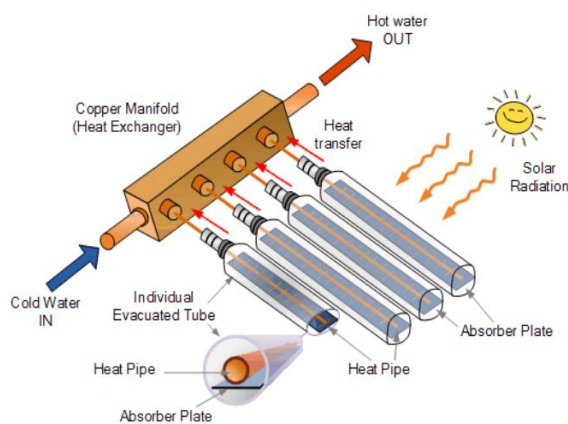


Fig -4: Concentrating Collector

2.6 Hybrid Solar Collector

Hybrid solar water heaters combine solar energy with other energy sources to ensure continuous hot water supply. They often integrate solar collectors with a heat pump or other conventional heating systems. Hybrid systems optimize energy utilization, using solar energy as the primary source and switching to backup heating when solar radiation is insufficient.

3. SOLAR STILLS

For the purpose of converting saltwater, brackish water, or wastewater into fresh water, solar stills are regarded as an essential part of the solar energy utilization process. The

glass cover, water basin, absorber plate, insulation, and distillate trough channel are only a few of the parts that make them up. They can be described as useful solar water distillation system that utilizes the sun's heat directly. Based on the idea that sun energy directly drives water evaporation, solar stills offer solar-powered desalination. People who live in distant places or small, isolated groups can utilize solar stills to distil, collect, and distribute high-quality drinkable water that is necessary for their daily life [12].

Solar still is one of the oldest methods of desalination process. It's principle of operation is the greenhouse effect, the radiation from the sun causes the water to evaporate inside a closed chamber. There are following types of solar stills:

- Single Slope Solar Still and Double Slope Solar Still with Single basin
- Spherical Solar still and Hemispherical Solar Still
- Tubular Solar Still and Pyramidical Solar Still
- Triangular Solar Still and Rectangular Solar Still

3.1 Slope Solar Still and Double Slope Solar Still with Single basin

Single slope solar stills are those that have just one cover plate or slope to catch the sun's rays. Solar radiation is used to heat the water, the water that is evaporated in the solar still's basin, is condensed on its bottom surface, and is afterwards collected in a collecting jar in pure water form. Active and passive single slope solar stills are the two types of single slope solar stills. In an active solar still, a heat source from outside is used to warm the water in the basin; in a passive solar still, no such external heat source is used to warm the water in the basin.

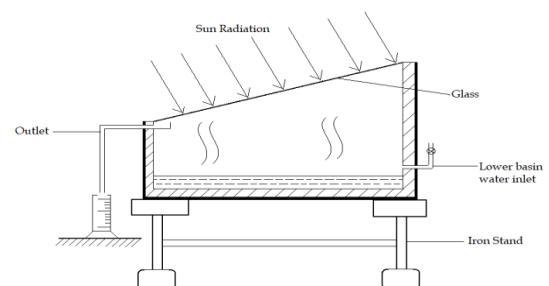


Fig -5: Single Slope Solar Still

3.2 Spherical Solar still and Hemispherical Solar Still

The slope or cover plate of an aspherical solar still has a spherical shape and is used to receive radiation from the sun. The spherical shape of the solar still increases the surface

area for incident radiation, increasing its overall efficiency. Salima Karroute et al. (2014) found that an asymmetrical spherical glass cover collects 4.62 L/m² of freshwater from 8 AM to 5 PM, despite having a 3.12 L/m² theoretical productivity. The spherical surface of the solar still causes an increase in the evaporation and condensation phenomenon, which also contributes to the solar still's increased productivity [13].

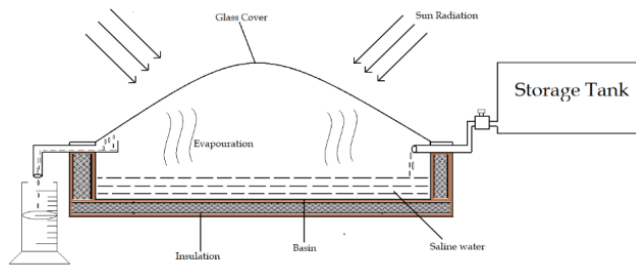


Fig -6: Hemispherical Solar Still

A hemispherical solar still is that which is equipped with a cover plate or slope which is in hemispherical shape. To hold the impure saline water that is desalinated with the aid of a hemispherical solar still, the basin associated with the hemispherical cover plate may be rectangular or any other shape, such as spherical or hemispherical. According to Basel I. Ismail et al. (2009), the daily yield ranged from 2.8 to 5.7 L/m² of absorber area. Another benefit of using hemispherical solar stills is a 33% increase in daily efficiency. According to the experiment, a solar still can produce distilled water from 50% of saline impure water input. Additionally, it was discovered that daily efficiency decreases proportionally as water depth rises [14].

3.3 Tubular Solar Still and Pyramidal Solar Still

Tubular solar still has a transparent cylindrical tube which is a part of the rectangular absorber that makes up the tubular solar still. The cover plate's cylinder-shaped shape is the only thing that differs. The saline water is heated using solar radiation that enters through a transparent tubular cover plate, and the process is repeated until freshwater is produced. Amimul Ahsan et al (2012) investigated that the use of polythene film was better than vinyl chloride sheet which is heavy and more costly. [15]

Pyramidal solar is still equipped with a top cover plate in the shape of a pyramid. It has two categories named triangular pyramid solar still and square pyramid solar still. Ravishankar Sathya Murthy et al (2014) found that the daily productivity increases by 8% and 15.5% when the surrounding air velocity is 3 m/s to 4.5 m/s [16].

3.4 Triangular Solar Still and Rectangular Solar still

Triangular solar still has a top cover in the shape of a triangle that is used to receive solar radiation coming from the sun.

The triangular solar still consists of two triangular shape cover plate that is supported by a glass supporting piece with an absorbing plate which is also in a triangular shape. Rajendra Prasad et al (2021) examined that adding the triangular solar still gave maximum yield which was 3.24 kg/m² and there was also an increase in efficiency by 39.24%. It had also been found that there was an increase in efficiency by 12.96% with the help of a modified absorber plate [17].

Rectangular solar still is equipped with a top cover plate which is in the shape of a right angle triangle and rectangular shape basin. Arunabh Saikia et al (2018) examined that the maximum output obtained on a sunny day was 662 ml of pure distilled water. It was also found that yield in the month of February, March, and April was nearly 400-410 ml. Abdallah et al (2015) found that the best inclination for single slope passive solar still is 15 degrees with respect to its yield and efficiency when compared to the different inclination angles of the cover plate such as 30 degrees and 45 degrees [18].

4. SOLAR COOKER

A solar cooker is a device that utilizes sunlight to cook food without the need for conventional fuels such as gas or electricity. It harnesses solar energy through reflective panels or surfaces to concentrate and trap the sunlight, converting it into heat. The basic working principle of a solar cooker involves three main components: a reflector, a cooking vessel, and an insulating enclosure. The reflector directs sunlight onto the cooking vessel, which absorbs the heat and cooks the food. The insulating enclosure traps the heat inside, creating a greenhouse effect and maintaining cooking temperatures. Solar cookers are a sustainable and clean cooking solution, promoting energy efficiency and reducing environmental impact. Solar cookers today fall within three main categories called solar panel cookers, solar box cookers and solar parabolic cookers.

It was discovered through experimental testing and enhanced solar cooker performance that solar ovens are more effective than solar cookers, but that solar ovens are more expensive, bulkier, and require more tracking time. Therefore, basic box cookers can overcome their drawbacks with some modifications. When the lateral surface of absorption was tilted, solar radiation acceptance enhanced (33% more), according to the observation. Here, two movable mirror boosters were used to increase the absorption of solar radiation. This led to an increase in overall solar efficiency of 24.6%, which is comparable to the performance of a solar oven. But it only had a negligible 10% impact on the price of this improved solar cooker. [19]

4.1 Solar Panel Cookers

This is the simplest type of cooker from the constructional view. In this cooker the solar radiation is concentrated by

flat panels which then reflects the Sunlight and focuses for cooking. [20] This cooker incorporates both the elements of parabolic and box type cooker. It can gain the temperature range of 95-120 degree C.



Fig -7: Solar Panel Cooker

4.2 Solar Parabolic Cookers

These types of cookers focus a lot of solar energy onto a very small area where a cooking pot is placed in the basin, using parabolic shape reflectors.(Figure-8). The heating capacity is high, so the care is to be taken to look the food at times because if the food is left unattended there is a possibility of burning of food. Solar cooker based on the parabolic dish collector with phase change thermal storage unit was examined. In one of the experimental setup, solar cooker with the phase change thermal storage unit was kept on the absorber plate of parabolic dish collector. During day time, acetanilide (phase change material) stores solar heat and during evening, solar cooker is kept in the insulator box. Then, the phase change material delivers heat to the food as it emits out the energy. In a study an ordinary solar cooker was compared with the solar cooker which was painted black and solar cooker with outer surface painted black along with glazing, the temperatures obtained for each type is 119 degree C, 175.4 degree C, and 186.3 degree C, respectively[21].



Fig -8: Solar Parabolic Cooker

4.3 Box type solar cookers

First Solar Cooker was invented by a French-Swiss Naturalist named Horace de Saussure in 1767 as the record goes. A solar box type cooker basically has a box which is insulated. It is topped with a transparent glass or plastic cover, this cover acts as a trap for solar energy. The solar radiation passes through the window, which is then absorbed by the walls, the bottom of the cooker. The walls and outer side of the box are painted with black color. Temperatures inside the box can reach about 140-150 degree C [22].

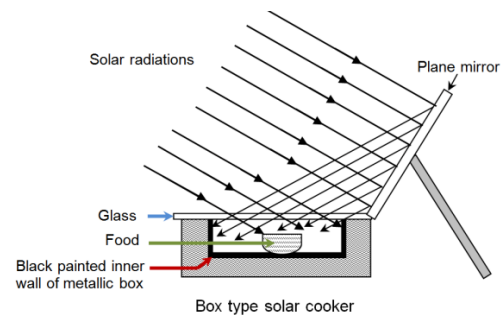


Fig -9: Box type Solar Cooker

5. SOLAR DRYER

A solar dryer is a device that utilizes solar energy to remove moisture from various materials, such as agricultural products, herbs, fruits, and textiles. It operates on the principle of converting solar radiation into heat energy, which is used to evaporate the moisture content in the materials. Solar dryers typically consist of a drying chamber or compartment, a solar collector or absorber, and an air circulation system. The solar collector absorbs sunlight and transfers the heat to the drying chamber, where the materials are placed. The air circulation system helps remove the moisture-laden air and replace it with drier air, facilitating the drying process. Solar dryers offer an energy-efficient and environmentally friendly alternative to conventional drying methods, reducing reliance on fossil fuels and improving the quality and preservation of dried products.

Solar dryers are available in a range of size and design and are used for drying of various agricultural products. Following criteria's are required for the classification of solar dryer:-

- 1) Air movement mode
- 2) Insulation exposure
- 3) Air flow direction
- 4) Dryer arrangement
- 5) Solar contribution

6) Type of fruit to be dried

Solar dryers are of the following types

5.1 Passive Solar Dryer

Passive mode dryer is also known to be natural convection solar dryer. The natural movement of air due to the buoyancy force affects the efficiency of this dryer. This drying can be further categorized as open sun drying and natural-circulation drying. Natural-circulation dryers also use passive air movement other than open solar drying. Heated air flows towards the drying object due to buoyancy force. A cabinet dryer also uses passive air circulation.

Islam, Islam, Tusar, & Limon [23] assessed three different types of passive solar dryers (thin tube chimney type, attic space type, and natural draft chamber) at natural conditions. The experiments were done by drying apple, pineapple, banana and guava from 10 AM to 4 PM for several days in different seasons. The natural draft performance was seen best with a 58.9% moisture removal rate, while for thin tube chimney type was 44.5% and 33.3% for attic space type chamber in 6 hours drying time. The rate of moisture being removed was analyzed after 1 PM and it was higher than before 1 PM because of the increase of solar radiation.

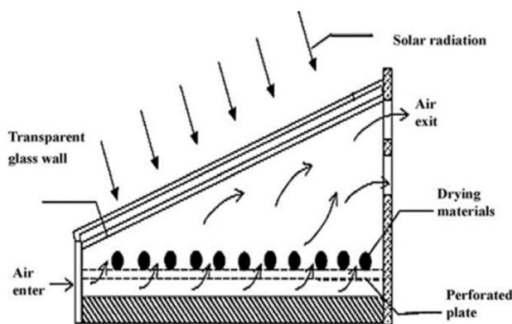


Fig -10: Schematic of Passive Solar Dryer

5.2 Active Solar Dryer

Active solar dryer is also called as forced convection dryer. The system utilizes solar energy for heating and is aided with electrical or fossil fueled engines or pumps to provide the air circulation. The external source (engines/pumps) are used to move the heated air from solar collector to the drying area. This type of dryer is ideal for crops with high moisture content like cabbage, papaya, kiwi, etc.

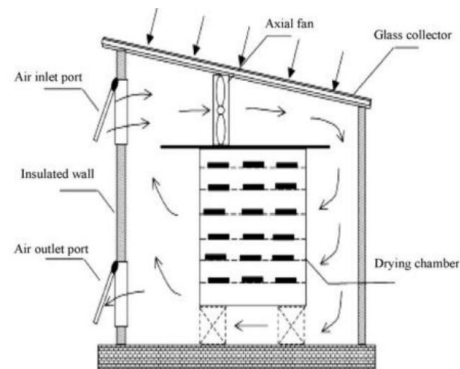


Fig -11: Schematic of Active Solar Dryer

Veeramanipriya & Sundari [24] conducted a study on the drying performance of a forced convection solar dryer that was aided with an evacuated tube collector and it was compared with natural sun drying. The air temperature gained at the outlet of the evacuated collector was 59-108°C, which was more significant than the ambient temperature, which was 33.5-35.5°C. The quality of dried fruit obtained was also better with a drying period of 5 hours, whereas open sun drying took 8 hours to reach moisture equilibrium.

5.3 Direct Solar Dryer

This dryer has transparent glazing which is made of glass or plastic, the products that need to be dried are kept in the chamber which is enclosed by this glazing. This is low cost dryer due to its simple construction.

Nabnean & Nimnuan [25] examined the performance of a household solar dryer of direct forced convection for frying banana. About five batches of banana with 10kg of bananas for each batch were dried. The temperature supplied in the dryer was in range of 35°C to 60°C between 8 AM to 6 PM. The result was compared with open sun drying. The solar dryer reduced the moisture content from 72% w.b. to 28% w.b. within 4 days, while the open sun drying reduced to 40% w.b. only during the same period. The solar dryer is more effective than the open sun drying since it can preserve high product quality and reduce 48% of the drying period than other one.

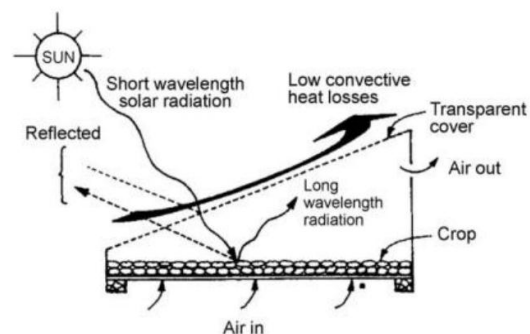


Fig -12: Cabinet Solar Dryer

5.4 Indirect Solar Dryer

This dryer consists of a drying chamber, a solar collector and a fan. The collector and chamber are separated which are connected by a flexible insulated conduit. The solar collector is placed inclined to receive maximum solar radiation. The fan transfers the heat through a medium of ducting to drying chamber. This results into products not coming in direct contact with the sun which avoids damage to the product.

R. Ouaabou et al [26] examined an indirect solar dryer by assessing the dryer characteristic and its effect on sweet cherry drying. The authors concluded that the solar dryer was less energy-intensive and affordable. The electrical heating cost was less than 5%. The indirect forced solar dryer had no significant impact on sweet cherry fruit quality, making the drying process more efficient than open sun drying.

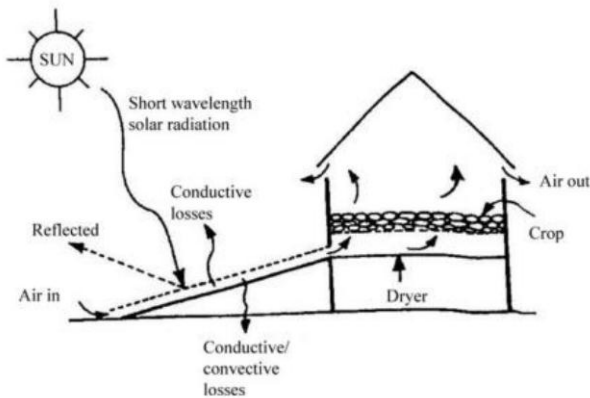


Fig -13: Indirect Solar Dryer

5.4 Mixed-mode Solar Dryer

The features of direct and indirect solar dryers are combined in mixed mode solar dryers [27]. A separate collector is attached which will preheat the air for this type of solar dryer before delivering it into the drying chamber. By using a mixed-mode solar dryer, the temperature will surge higher than the ambient in a shorter period which can help to attain suitable moisture level in the dried product [28]. However, such a solar dryer has a complex design, and a higher initial cost is needed [29]



Fig -14: Mixed-mode Solar Dryer

The performance of a mixed-mode solar dryer with and without phase change material (PCM) was analyzed by Joshua et al [30]. It was found that the drying efficiency of the solar dryer with the PCM was higher than without PCM, 30.34% and 23.25%, respectively, for drying banana and 30.28% and 24.26%, respectively, for pineapple.

3. CONCLUSIONS

- This paper presents the study of different solar devices that are gaining attention due to increase in the shift towards the non-conventional use of energy to contribute in reducing burden on the conventional energy sources.
- The solar water heater of different configurations were studied with their working and respective advantages. The water heater configuration changes according to the requirement from the system.
- The solar cooker is also gaining grip as there are advancements in the cooker system to reduce the cooking time and reduce dependability on polluting resources in the rural areas.
- The solar still of different types has been highlighted and it is one of the feasible methods to obtain fresh water for daily use where access to freshwater is very limited to no access as in case of coastal areas. The different advancements contribute to increase the efficiency to gain more yield.
- The paper also presents the highlighted studies on solar drying system with its types and their respective research studies to maximize the yield and ways to increase the efficiency. This paper gives overall study of different solar devices that can be integrated to get the optimized design to form an integrated solar device.

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Vikrant P. Katekar
Research Scholar, Centre for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Powai, Mumbai, Maharashtra, India
Email Id:
vpkatekar@gmail.com

BIOGRAPHIES



Aditya Pradeep Todmal
BE Student at PVG'S COET & GKPIOM,
Pune 09, Maharashtra, India.
Email Id:
adityatodmal123@gmail.com



Ayush Deepak Mali
BE Student at PVG'S COET & GKPIOM,
Pune 09, Maharashtra, India.
Email Id:
ayushmali11@gmail.com



Sarang Dattatraya Kale
BE Student at PVG'S COET & GKPIOM,
Pune 09, Maharashtra, India.
Email Id:
sarangdk0508@gmail.com



Ganesh V. More
Department of Mechanical Engineering,
Pune Vidyarthi Griha's College of
Engineering and Technology and G. K.
Pate (Wani) Institute of Management,
Pune 09, Maharashtra, India.
Email id:
ganeshmr135@gmail.com