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Development and performance assessment of a hybrid solar cabinet dryer for fish drying

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Abstract: The fish products can be stored for longer period in dry condition, but most of the fresh fish in remote areas of our country are spoils due to lack of proper preservation. To overcome this problem, hybrid solar dryer can play an important role to make drying continuous during night and daytime also off sunshine hours. In this project, a hybrid solar cabinet dryer has been designed, constructed, and performance tested for fish drying. The dryer consists of a drying chamber, solar collector, two trays of dimensions (60×60) cm and paraffin wax as PCM. It also consists of photovoltaic cell modules, heating element, electric battery, and other electric equipment such as inlet and outlet fans. The dryer has been operated as both a solar energy dryer during normal sunny days and a hybrid solar dryer during cloudy days. Paraffin wax system inside drying chamber absorbed heat energy in Sunny time. At the same time the battery is charged from the solar system and therefore the water kept in the tank reaches a certain temperature by absorbing heat from nature, which provides heat by circulating the water inside the drying chamber during inclement weather. Electric fans are used at the inlet of the solar collector and outlet of the dryer to maintain adequate air flow inside the drying chamber. During the night and cloudy weather paraffin wax and heater system deliver heat to maintain the set temperature in drying chamber. The grain bed in the dryer is heated by air that comes from a separate solar collector, and at the same time, the drying cabinet collects solar energy directly through the transparent walls and roof. The dryer demonstrated the capacity to dry fish to an appropriate moisture level in a reasonable amount of time, and concurrently, it insured that the fish would be of high quality. The drying rate of hybrid solar dryers is evaluated on fresh fish and compared with solar dryers and sun drying under the same climatic conditions.

1. Introduction

Dried fish serves as a significant protein source within the context of Bangladesh. A sizable number of people live in coastal, central, and north-eastern regions, particularly in Sylhet, Mymensingh, Chittagong, and Cox's Bazar. Shutki, also known as dry fish, is a highly favored food product that enjoys widespread consumption in Bangladesh (Alam 2005). A significant portion of the population in Bangladesh relies on fish drying as a means of sustenance. In contemporary times, the significance of dry fish in the economic landscape of Bangladesh cannot be overstated. In the context of Bangladesh, the process of fish drying is traditionally conducted using several methods, such as spreading the fish on mats crafted from split bamboo, utilizing concrete floors, employing raised platforms, and employing bamboo poles and bars. Significant losses are incurred due to the delayed nature of the drying process. Every year, a significant amount of dried fish is subject to spoilage as a result of inadequate drying, preservation, and storage infrastructure, particularly in adverse weather conditions (Reza et al. 2005). The practical application of sun drying has been extensively utilized. Nevertheless, the process of drying has several drawbacks. These include the potential for product contamination from dust, filth, and other undesirable substances (Panchal et al. 2013), making it susceptible to losses due to insect infestation, animal

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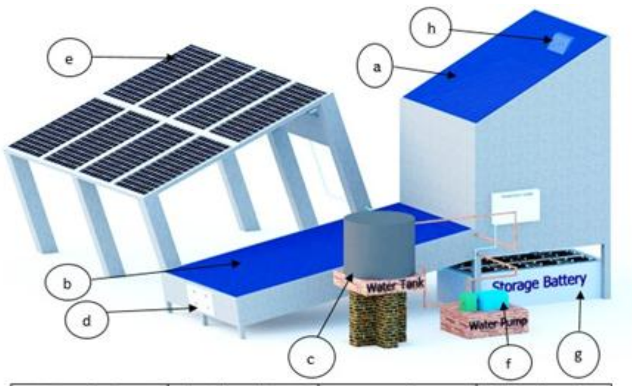
interference (Prakash and Satyanayarana 2014). Additionally, drying methods often require a significant amount of space and are particularly labor-intensive, especially in wet seasons. In order to address these disparities, a range of solar dryers have been produced. In the realm of solar energy use (El-Shiatry et al. 1991), various types of solar dryers have been identified (Dronachari and Shriramulu 2019), including direct type solar dryers (Bolaji and Olalusi 2008), indirect type solar dryers (Zoukit et al. 2019), mixed type solar dryers (Bolaji and Olalusi 2008; Forson et al. 2007; César et al. 2020), and hybrid solar dryers. One significant limitation of a solar energy dryer is its reliance on daylight hours, as it necessitates sufficient solar radiation to facilitate the conversion of solar energy into heat. A significant proportion of contemporary solar dryers are devoid of supplementary heating mechanisms as they are designed exclusively for diurnal operation. The implementation of measures to enhance process efficiency, such as reducing drying time and minimizing the production cycle's dependence on weather conditions, would be a favorable advancement. This has the potential to enhance the quality and quantity of processed products, contributing to their sustainability. Therefore, it is logical to consider innovative solar drying solutions that offer the additional advantage of an extended drying period, enhanced productivity, and increased reliability by supplementing heat (Vásquez et al. 2019), during days with limited radiation and operating at night or during periods of low solar radiation. In numerous developing countries, particularly in coastal regions, farmers and processors often face challenges related to the lack of access to grid-connected electricity and other non-renewable energy sources (Ahmed et al. 2018). These limitations, characterized by their unavailability, unreliability, scarcity, or high cost, contribute to a decrease in expected profits as they hinder appropriate post-harvest processing activities. To address the issue of uninterrupted drying in the absence of solar radiation, it becomes necessary to augment a solar energy drying system with an additional energy source, such as a hybrid solar dryer equipped with an energy storage system. Numerous scholarly investigations have been conducted to explore the utilization of photovoltaic (PV) (Barnwal and Tiwari 2008), modules for powering forced convection dryers. Among this research is the development of a forced convection solar energy dryer that operates using PV technology (Adelaja and Ojolo 2010). The present study is being carried out at Dhaka University of Engineering and Technology, located in Gazipur, Bangladesh. The local area encounters a peak temperature of roughly 35 °C on clear and sunny days within the months of July to October. Conversely, concurrently, the highest temperature seen within the drying chamber reaches approximately 67 °C. The temperature is twice as high as the surrounding environment, presenting a favorable condition for the construction of hybrid solar cabinet dryers. Insufficient data is available regarding the specific design aspects of a hybrid solar cabinet drier intended for the purpose of fish drying and incorporating an energy storage system. The primary objective of this project was to design and construct a hybrid solar cabinet dryer integrated with an energy storage system in order to enhance the efficiency of fish drying. This was achieved by lowering the overall drying time.

2. Methodology

A hybrid solar-energy dryer has been conceived and manufactured utilizing materials that are easily accessible in the local area (Babarinsa et al. 2006). The basic components of the hybrid solar dryer are illustrated in Figure 1. These components include the drying chamber, the drying tray, the solar collector, the solar panels, the solar battery, and the water tank (Onigbogi et al. 2012; Amer et al. 2010). The drying chamber (a) of the hybrid solar dryer has the dimensions of 102 cm in height, 72 cm in length, and 65 cm in width. The drying chamber is constructed out of wooden flanks, and the inside walls are coated with G.I. sheet that has been painted black. This helps the chamber absorb heat more effectively. The corrosive-resistant wire mesh was used to construct the wall of the drying chamber that measured 60 cm × 60 cm and served as the backdrop for the drying trays. The dryer includes an exhaust fan (h) that is 88 cm in height and is positioned on the very top of the drying chamber. A direct current extractor fan (d) to supply hot air while leaving moist air from the items to be released into the atmosphere. The upper section of the drying chamber is enclosed in see-through glass that measures 4 millimeters in thickness. The wall of the drying chamber is attached to the solar collector (b), and it is tilted at an angle of 21 degrees to the horizontal in order to give an inclination that is equivalent to that of the sun (Eke 2014). The solar collector is made up of an absorber plate that is made out of a sheet of G.I. that has been coated black and a piece of transparent glass that is 4 millimeters thick and only lets



a. Drying chamber	b. Solar collector	c. Water tank	d. Air flow fan
e. Solar panel	f. Water pump	g. Storage battery	h. Exhaust fan

Figure. 1: Hybrid solar dryer.

sun radiation through. To prevent heat from escaping through the bottom, the absorber plate has been insulated. In order to facilitate the flow of air into the dryer, the lower front side of the collector has been

equipped with a vent for the air. In order to stop insects from getting inside the dryer, this opening has been covered with a mosquito net. The stand has wooden legs at each of its four corners. At the mouth of the solar collector, hot-water copper tubes are twisted together to create a circulation system for the water. During the hours that the sun is shining, tubes made of paraffin wax are fastened to the two side walls of the drying chamber. This causes the paraffin wax to transition from the solid phase to the liquid phase. In addition, the dryer comes equipped with a DC blower fan (d) and a 300-watt power heater both of which may be found at the base of the drying chamber. The system that is being utilized to power the device is powered by a battery (g) that has a power rating of 200 Ah and six solar panels (e) that each have a power rating of 180 W. In order to get an accurate reading of the temperature inside the chamber, there is a temperature sensor placed smack dab in the middle of it. The control panel, includes a switch for turning the lights on and off.

2.1. Drying Chamber

As can be seen in Figure 1, the drying chamber (a) is constructed out of wooden planks and measures 102 centimeters in height, 72 centimeters in length, and 65 centimeters in width. The chamber consists of a combination of two geometrical elements, one of which has the shape of a cube, and the other of which has the shape of a triangular prism at the head section of that. On the interior of the drying chamber, noncorrosive GI sheet is utilized. It has an exhaust outlet section at the top, and it is coupled with the solar collector at the bottom, so air that has already been heated by the solar collector can pass through it. Two trays have been assembled inside the chamber, and they are both positioned in such a way that

the space between each tray is a third of the space that exists between the bottom most tray and the bottom of the chamber. The purpose of making this gap is to provide equal drying facilities to the entirety of the fish product that is being dried inside the drying chamber, which will ultimately result in an increased drying rate. The upper part of the chamber is enclosed by a sheet of clear glass that is four millimeters thick and is angled at a 21 degree angle from the peak of the triangular portion.

2.1.1. Drying Trays

The shape of drying trays that measure 62 centimeters by 62 centimeters is depicted in Figure 1. The wire mesh (net) used to construct the non-corrosive drying tray is encased in a wooden frame that completely surrounds the tray. For reasons of hygiene, this is the best option for a solar cabinet dryer. The size of the tray plays a role in determining the capacity of the dryer.

2.1.2. Solar Collector

The solar collector (b) is made with a length of 147 cm and a width of 62 cm as shown in Figure 1. The drying chamber's bottom (the side across from the door) is the same width as the solar collector, which is a cube-shaped structure. Air can only enter the drying chamber through the air inlet part because of how the solar collector is attached to it. From the chamber's base to the ground, the solar collector is attached to the chamber at an angle of 21°. The lower part of the terminal piece of the solar collector is constructed with an air entrance. A non-corrosive GI sheet is attached to the bottom of the solar collector, and dark black paint has been applied to it. A 4mm thick transparent glass sheet covers the collector's upper section (Babar et al. 2020).

2.1.3. Solar Panels with Storage Battery

Solar panel (e) with storage battery (g) is shown in Figure 1. A PV system must produce enough energy to meet its own needs as well as the energy requirements of the loads. The size and arrangement of the solar panels were then adjusted to maximize energy output while minimizing energy usage.

A significant part of standalone PV systems is the battery. When there is little sunlight, the batteries or the PV modules together provide load operation during the night.

One must prepare for periods of overcast weather and design a reserve energy capacity stored in the batteries for the PV system to operate safely. The amount of time the system is independent on the energy produced by the PV modules is measured in days and is referred to as this reserve capacity. For the sake of this design, the system's autonomy is assumed to be 24 hours (or one day).

2.1.4. Solar Panel with Storage Battery to AC/DC Power

Both AC and DC loads can be powered by photovoltaic (PV) solar panel (e) as shown in Figure 1. The UPS or inverter powers the AC load, which serves as a backup source of energy for battery storage. After getting backup storage, it can be operated without batteries if it is not required at night or during severe weather. As a result, the inverter or UPS will supply power from the solar panels directly to the AC load. Additionally, the charge controller's DC load terminal is the only one that is directly connected to the DC load. A 12V solar panel is directly linked to the 12V charge controller, as shown in the solar panel diagram below. The positive and negative battery terminals of the charge controller are where the battery and inverter are linked. The charge controller's DC output terminal is likewise wired up with a DC load. The inverter output terminals are linked to the 220V AC load, which includes the fan, light, heater, and pump.

Both AC and DC loads can be powered simultaneously by the entire system. The system power is used as required to prevent the battery's charging time and rate from being significantly slowed down by other loads connected to the PV panel (Hussein et al. 2017). Depending on the needs of the system, the different parts (solar panels and batteries) may be connected in series, parallel, or a mix of series and parallel connections.

The good news is that since the entire power conversion process (from solar power to battery) is fully automatic through an automatic UPS or inverter, no additional manual or automatic changeover or automatic transfer switches are required to transfer power between battery and solar panels at the load point (Okoroigwe et al. 2013).

2.1.5. Control Board

The control panel is used to manage several functions on the hybrid solar dryer. It consists of the following parts, such as

a. Control switch.

b. Thermostat

The temperature sensor, which is positioned inside the drying chambers, is connected to a dryer that can be tuned to the desired temperature. The control switch uses the sensor's temperature input to determine how much current to allow to flow through the heating components. The heating elements are manually shut off when the temperature rises over the set temperature and manually turned on by the control switch when the temperature falls below the set value.

2.1.6. Heat Collection in a Water Tank with Water Flow

A water tank (c) is used in hybrid solar dryer systems as shown in Figure 1. On a full sunny day, it receives heat from the sun and reaches a certain temperature. By the end of the day, the water temperature in the tank had risen to over 49 °C from an early morning temperature of about 15 °C. It then helps to raise the water to the set temperature (70 degrees) through the electric water heater placed inside the tank. When the temperature inside the dryer drops in bad weather, water is circulated inside the dryer to increase the temperature. As a result, the temperature inside the dryer increases, which helps in drying the fish. In this method, the water is raised from a temperature of 49 degrees to 70 degrees, and as soon as the water reaches 70 degrees, the electric heater automatically stops heating the water. This procedure continues up to the end of the drying.

2.1.7. Fan or Blower

Two electric fans (d) are connected to the inlet portion of the solar collector to supply the heat absorbed by the solar collector inside the drying chamber as shown in Figure 1. Both fans are driven by the power coming from the battery. The hot air absorbed by the solar collector is supplied to the drying chamber through the electric fan. It receives moisture from the fish product and releases the air through the exhaust fan at the outlet of the chamber.

The motor fan arrangement maintains the airflow inside the dryer. A uniform reduction in the duct's height causes the air velocity to increase after being thrown radially into the tapered duct from an axial air intake.

Now that hot air is being cycled into a motor fan setup to keep the drying chamber's temperature consistent, the necessary temperature can be reached faster.

2.1.8 Electric Heater

A 300-watt electric heater is connected inside the drying chamber to keep the temperature of the drying chamber up to a certain level due to bad weather, cloudy day and at night, which is powered by the battery. The fish product absorbs heat and is capable of drying out (Sharma et al. 1993).

By utilizing a pair of heating components and exposing the collecting plate (made of glass) to sunlight, the air within the heating chamber undergoes heating. Subsequently, the drying chamber is infused with the aforementioned heated air.

2.1.9 Paraffin Wax

Paraffin wax used as PCM (Phase Change Material) in drying chamber as shown in Figure 1. Inside the drying chamber, there are tubes of paraffin wax attached to the two side walls, which absorb heat and change into liquid phase during the day time. It reaches a certain temperature by absorbing heat from the sun during the day. When the paraffin wax kept inside the drying chamber reaches a temperature of 48 °C, it starts to change from solid phase to liquid phase. This phase change can be maintained as long as the weather outside is good. When the outside temperature begins to decrease due to bad weather, cloudy day and at the end of the day, the temperature inside the drying chamber also decreases. As a result, the paraffin wax kept in the chamber continues to release heat until the solid phase reaches 48 °C which helps to dry the fish product (Agarwal and Sarviya 2017).

3. Results and Discussion

3.1. Introduction

The results, analyses, and issues that came up during the design and construction of a hybrid solar cabinet dryer are covered in this chapter. This project will be assessed once it has been developed and finished in order to gauge its efficacy and confirm that the stated goals have been met. The feasibility of the dryer from a technical standpoint will be investigated during this test. The experiment started at 8:30 in the morning on a day when the average temperature was 27 °C. During the ten-hour test, the hybrid solar drying method, the solar dryer, and the open sun drying method all required the same length of time to reduce the moisture content of fresh fish from 80% to 31.8%, 50.4%, and 59.4%, respectively. This was determined by measuring the amount of time needed to dry the fish using a solar dryer. During the test, the interior of the hybrid solar dryer reached a maximum temperature of 67 °C, and its drying chamber reached a maximum temperature of 54 °C, even though the maximum ambient temperature was 35 °C. The quality of fish samples dried using the hybrid dryer is much higher than that of fish samples dried using solar or sun drying procedures (Babarinsa et al. 2006). It has been demonstrated that higher temperatures create a faster rate of drying, which results in a shorter amount of time needed for drying (Reyes et al. 2014).

3.1.1. Performance assessment of the hybrid solar dryer

The materials utilized to test the hybrid solar dryer are listed below: fish, wet bulb thermometer (model: HTC-2), and digital weighing machine (model: WPCS-DS982).

Throughout the day and night of operation, the dryer has been left in a bright area free from any kind of cover. The solar collector and the heating coil element are two heating sources that can be used separately or together. When there is a lot of sun radiation, it is transported into the drying chamber through the inlet window by the forced convection system and is absorbed by the collecting plate (Phadke et al. 2015), which is painted black. By doing this, the moisture that is released while drying is removed. However, when the temperature drops, it becomes necessary to continue drying into the night to get the products dry enough to store, or when the weather is terrible, the thermostat activates the heater to help with drying. Additionally, drying is done at night using electric heaters housed in a water tank, paraffin wax, and water that has been heated during the day and stored as heat energy. Electricity is produced from solar energy by photovoltaic solar panels. The heater, fans, and control system are all powered by the electricity generated, which also serves to recharge the battery. In order to retain charge for use at night or in inclement weather, the battery functions as a storage bank.

The drying chamber, solar collector, rack and trays, heater, water tank, fan/blower, paraffin wax, solar panel, solar battery, and control panel are the key parts of the hybrid solar dryer. Mild steel, galvanized sheet and wire, plywood, a solar panel, a solar battery, an on/off switch, and a thermostat (thermocouple) were all employed in the construction. Galvanized sheet and plywood were used in the construction of the 0.403 m^3 drying chamber. In order to minimize heat loss from radiation, it was painted black. A galvanized sheet that is noncorrosive is used to cover the interior of the drying chamber. Wood was used to build the rack, which was positioned to make it simple to insert separate trays 0.2 meters apart. To allow hot air to circulate and pass through the fish being dried, the trays were built of plywood and their bases with non-corrosive wire gauze (net).

The fish that were employed in this investigation were procured from the market place in the vicinity. Fish are inspected for their firmness, color consistency, and size uniformity, and then samples are sorted and chosen from the lot. After giving them a thorough wash with tap water, rinsing them with distilled water, and finally drying them with absorbent paper, they are considered clean (Amer et al. 2010). Following the cleaning process, the fish are divided among three trays of the same weight for the purpose of the study. Each tray contains one hundred and fifty grams (or half a kilogram) of fish. Three trays are used to dry the fish inside the chamber, two of which are placed inside the chamber, while one tray is kept outside at room temperature. After waiting for thirty minutes, the fish were weighed with a digital weight meter to quantify the amount of moisture that was extracted from the fish. Both the temperature inside of the drying chamber and the ambient temperature outside are measured with a digital thermometer. During inclement weather and at night, the temperature within the drying chamber is kept at the appropriate level by means of a combination of electric heating and the circulation of hot water. In addition, paraffin wax was utilized inside the dryer. This wax absorbs heat from the sun and an electric heater during the day, which causes it to transform from its solid phase into its liquid phase. When the temperature drops at night and there is poor weather, the paraffin wax loses heat and transitions from a liquid phase to a solid phase. As a direct consequence of this, it is feasible to keep the temperature within the dryer stable for a predetermined amount of time. In addition to that, the temperature at which the paraffin wax undergoes its phase shift is measured with a digital thermometer. It has been determined and recorded that the average weight of each dry mass was taken. The temperature of the drying chamber is monitored and kept under control by the thermostat located on the control panel.

3.1.2. Determining the Efficiency, Amount of Moisture Removed and Drying Rate of the Hybrid Solar Dryer

Hybrid solar dryer efficiency indicates the overall thermal assessment of a dryer, including the efficiency of a solar collector, drying chamber and other supplements added to the system. The efficiency of the constructed hybrid solar dryer is calculated using the formula below as follows (Leon et al. 2002; Bennamoun 2012), For hybrid solar dryers, the efficiency is calculated as follows by the equation below

$$\text{Efficiency, } \eta = \frac{W \times L}{(I \times A) + P_f + P_h} \qquad \text{(i)}$$

Where,

η = Hybrid solar dryer efficiency.

W = Weight of water evaporated from the fish (kg)

L = Latent heat of vaporization of water (J/kg)

I = Radiation of solar (W/m^2)

A = Solar collector area (m^2)

P_f = Power consumption of fan (watt)

P_h = Power consumption of hater (watt)

The amount of moisture removed is calculated by using the following formula below as (Ehiem et al. 2009).

$$\text{Moisture Removed, } M_R = \frac{M_p \times (M_i - M_f)}{(100 - M_f)} \qquad \text{(ii)}$$

Where

M_p = Weight of fish before testing (kg)

M_i = Moisture content of fish before testing

M_f = Moisture content of fish after testing

The drying rate of hybrid solar dryer has been calculated by using the formula as given (Aliyu et al. 2013).

$$\text{Drying Rate} = \frac{Amount\ of\ moisture\ removed\ (Kg)}{Total\ drying\ time\ (Hour)} \qquad \text{(iii)}$$

3.1.3. Variation of Drying Rate

Figure 2 depicts the variations in the drying rates that have occurred. When the hybrid solar dryer is used to dry fish, it has been shown that the drying rate of the fish falls steadily with the drying time when the average air velocity is 1.2 m/s. During the course of the experiment, the rate at which fish were dried in the hybrid solar dryer was 1.75 times faster than the rate at which fish were dried in the open sun. It took a total of 15 hours to dry the fish product using this method, which resulted in a drying rate of 0.0322 kg/hour on average during the operation of a hybrid solar dryer during the course of 10 hours of observation. This result was better than the 0.0241 kg/hour that was reported by (Chavan et al. 2008), for a solar-biomass hybrid photovoltaic cabinet dryer designed

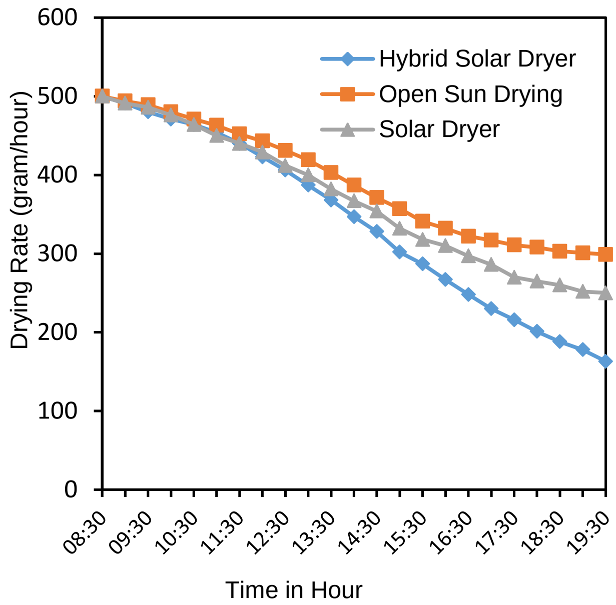


Figure. 2 : Variation of drying rate.

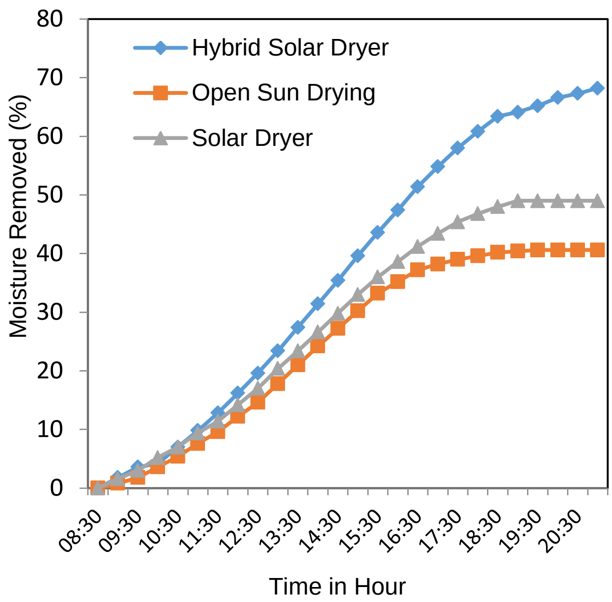


Figure. 3: Variation of moisture removed with respect to time.

for use in tropical environments. It was determined that the solar dryer dried at a rate of 0.0248 kg/hour, and it took 25 hours to dry the fish product using this approach. The open sun drying method dried at a rate of 0.01845 kg/hour, and it took 36 hours to dry the fish product using this method. On the other hand, the hybrid solar dryer dried the fish product in just fifteen hours.

3.1.4. Variation of Moisture Removed

The changes in the moisture removed (%) with the drying time are shown in Figure 3. When the average air velocity is 1.2 m/s, it has been observed during the experimental period that the moisture removed from the fish dried in the hybrid solar dryer is faster than the open-sun drying method. The moisture removed from fish is faster during the first 7 or 8 hours in the hybrid solar dryer, but afterwards the moisture removed becomes low due to low moisture content. During the 10 hours of observation in this process, the average moisture removed by hybrid solar dryers was 6.82%, and this result was higher than the 5.93% reported by (Chavan et al. 2008), for the solar-biomass hybrid photovoltaic cabinet dryer for the tropics. The solar dryer method is 4.96%, and open sun drying is 3.79%.

Table 1 presents the speeds of drying, the amount of moisture that is eliminated, and the temperature as they change over the course of time. The evaluation started at 8:30 in the morning on a day when the average air velocity was 1.2 m/s and the ambient temperature was 27 °C. It has been found that the drying rate of fish dried in a hybrid solar dryer, as well as the amount of moisture removed, declines steadily with the length of time spent drying the fish. This is the case even when the amount of time spent drying the fish does not affect the total amount of moisture removed. When utilizing the hybrid solar drying process, the initial moisture content of fresh fish can be reduced from 80% to 31.8% in as little as 10 hours. This is in contrast to the solar dryer and open-sun drying methods, both of which require the same number of hours to achieve moisture reductions of 50.4% and 59.4%, respectively, than the solar dryer does. During the course of the experiment, it was discovered that the greatest temperature that could be attained within the hybrid solar dryer was 67 °C, in contrast to the open sun drying method, which reached a maximum temperature of only 36.8 °C, and the solar dryer's drying chamber, which reached a maximum temperature of 54 °C. In the midst of all of this activity, the temperature of the paraffin wax within the drying chamber rises to 69 °C. This result was greater than the 59.6 °C maximum drying chamber temperature published by (Barnwal and Tiwari 2008), for a hybrid photovoltaic integrated greenhouse dryer and the 62.4 °C maximum drying chamber temperature reported by (Chavan et al. 2008), for a solar-biomass hybrid photovoltaic cabinet dryer for the tropics. (Barnwal and Tiwari 2008), and (Chavan et al. 2008), were both referring to the temperature of the drying chamber. The temperature range that existed inside the hybrid dryer chamber was noticeably higher than the temperature range that existed inside the solar dryer chamber as well as

Table 1: Drying rate at different dryer system.

	Hybrid solar dryer			Solar dryer			Open sun drying			Paraffin wax
	Weight (gram)	Moisture removed (%)	Temperature (°C)	Weight (gram)	Moisture removed (%)	Temperature (°C)	Weight (gram)	Moisture removed (%)	Temperatu re (°C)	Temperature (°C)
08:30	500	0	34.6	500	0	33.2	500	0	27.2	34.6
09:00	491	1.8	36.3	492	1.6	33.5	496	0.8	27.6	36.5
09:30	482	3.6	38.5	485	3	35.2	491	1.8	28.8	38.7
10:00	479	4.2	39.8	474	5.2	36.6	482	3.6	28.9	39.9
10:30	465	7	41.6	465	7	38.4	473	5.4	29.6	41.9
11:00	451	9.8	42.8	453	9.4	39.1	462	7.6	30.2	43.1
11:30	436	12.8	45.3	443	11.4	42.3	452	9.6	32.6	45.7
12:00	419	16.2	48.7	429	14.2	43.6	439	12.2	33.3	49.0
12:30	402	19.6	52.4	415	17	46.8	427	14.6	35.1	52.7
13:00	383	23.4	56.2	398	20.4	48.6	411	17.8	35.2	57.3
13:30	363	27.4	59.8	383	23.4	52.7	395	21	35.9	60.4
14:00	343	31.4	60.6	367	26.6	53.3	379	24.2	36.7	61.5
14:30	323	35.4	63.8	351	29.8	54.2	364	27.2	36.8	64.6
15:00	302	39.6	66.4	335	33	54.5	349	30.2	37.1	67.9
15:30	282	43.6	67.2	320	36	52.4	334	33.2	37	68.8
16:00	263	47.4	67.3	307	38.6	51.1	324	35.2	36.4	70.2
16:30	243	51.4	65.2	294	41.2	50.4	314	37.2	35.6	69.7
17:00	226	54.8	63.8	283	43.4	49.2	309	38.2	35.3	68.5
17:30	210	58	60.2	273	45.4	46.2	305	39	35.2	63.6
18:00	196	60.8	59.4	266	46.8	44.3	302	39.6	35.2	62.8
18:30	183	63.4	57.3	260	48	43.2	299	40.2	33.6	61.2
19:00	171	65.8	55.7	255	49	41.5	298	40.4	33.4	59.3
19:30	159	68.2	54.2	252	49.6	39.4	297	40.6	32.2	58.4

the temperature of the surrounding environment throughout the vast majority of the daylight hours. The quality of fish samples that have been dried using the hybrid dryer is significantly higher than the quality of fish samples that have been dried using solar or sun drying methods. It has been established that an increase in temperature results in a faster drying rate, which, in turn, reduces the amount of time that is required for the drying process.

3.2. Discussions

The results during the test period are analyzed to determine the technical feasibility of the hybrid solar dryer. The test starts at 8:30 a.m. when the ambient temperature and the inside dryer temperature are found to be 26 ℃ and 30 ℃ respectively. When the maximum ambient temperature is 35.℃, at the same time the temperature at the outlet of the solar collector, solar dryer, and paraffin wax are found 49 ℃, 54 ℃, and 57 ℃, respectively. In the same process, the maximum drying chamber temperature was found 67 ℃ and paraffin wax temperature 69 ℃ by using hybrid system. When the temperature drops during cloudy weather and at night, the temperature in the drying chamber continues until the paraffin wax solidifies. It takes approximately an hour and a half for the paraffin wax to return back to a solid state of 48 °C. During the ten-hour test, it took the same amount of time for the hybrid solar drying method, the solar dryer and the open sun drying method to reduce the moisture content of fresh fish from from 80% to 31.8%, 50.4%, and 59.4% respectively. For hybrid solar dryers, the average drying rate and efficiency are calculated to be 0.03272 kg/h and 74.4%, for solar dryers 0.02136 kg/h and 52.7%, and for open sun drying 0.01796 kg/h and 39.4%. In comparison to solar open sun drying techniques, hybrid solar dryers produce fish samples of higher quality. According to the findings of this research, a hybrid solar dryer that uses photovoltaic solar

panels is a potential method for preserving fish. It can shield fish from waste and deterioration for long-term storage.

4. Conclusion

A hybrid solar dryer that employs photovoltaic (PV) solar panels to power the heating element and charge the battery, which contains a storage energy system, has been developed, and it has been used to investigate how fish products behave when they are dried. Within the drying chamber, PCM (Phase Change Material) in the form of paraffin wax is utilized. It does this by soaking up heat from the sun during the day, then releasing that heat within the drying chamber until it reaches the temperature necessary to enter the solid phase, which is 48 degrees Celsius. The performance demonstrated that the hybrid solar dryer is able to generate a temperature within the drying chamber that is 67 degrees Celsius, the solar dryer a temperature of 54 degrees Celsius, and the maximum open sun drying ambient temperature is 35 degrees Celsius for the majority of the daylight hours.

The following are some of the factors that support the adoption of hybrid solar dryers.

a. The hybrid solar dryer has a modular design with several valuable features that have been developed.

b. The design of hybrid solar dryer is such a way that it is easy to operate and handle.

c. During good weather during the day the storage battery is charged by the solar panel which provides the charge to run the heating system during bad weather and at night.

d. During the experiment, without fish loading inside the drying chamber, the maximum temperature has found to be 71 °C, and the paraffin wax temperature was 74 °C, when the maximum ambient temperature was 37.2 °C.

e. During the experiment, the maximum temperature of the drying chamber was found to be 67 °C, and the paraffin wax temperature is 69 °C, when the maximum ambient temperature was 37.4 °C.

f. Paraffin wax efficiently stores solar energy and is supplied with three hours and twenty minutes of backup heat inside the drying chamber.

g. In 10 hours of continuous drying, the moisture removed from the fresh fish is 68.2% through the hybrid solar dryer.

h. The average drying rate of fish after 10 hours of continuous drying is calculated to be 0.03272 kg/h through the hybrid solar dryer and open sun drying method is found 0.01845 kg/h.

i. It has also been proven that hybrid solar dryers, which combine solar energy with a heating element driven by a photovoltaic solar panel, are more efficient than other drying methods.

Disclosures

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