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Modification and performance evaluation of IoT-enabled solar dryer for fish drying

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Abstract

This study presents the modification and performance evaluation of an Internet of Things (IoT)-enabled solar dryer fitted for fish drying applications. Traditional solar dryers often lack precision control and monitoring mechanisms, resulting in suboptimal drying outcomes. To address this, we integrated IoT technology into the solar drying system, allowing user-interface monitoring and control of critical parameters. The modified solar dryer features sensors (DHT22, Lux) capturing data on temperature, humidity, and ambient conditions, which are relayed to a central control unit. This integration enables dynamic adjustments for optimal drying conditions. Key performance indicators, namely % moisture loss efficiency and drying rate were evaluated to gauge the effectiveness of the system. When compared to traditional sun dryers, three experimental trials using fresh fish samples under various conditions showed a considerable improvement in moisture loss efficiency. In contrast to 67% when drying in the sun, the percentage of total moisture loss in fish after 22 hours in the drying chamber was found to peak at 85%. Additionally, there was a notable improvement in the drying rate, demonstrating the IoT-enabled solar dryer's potential for effective fish drying. Sun-dried fish had an hourly average drying rate of 11.64 grams, whereas the IoT-based solar drier achieved an average of 14.77 grams per hour. With a decent user interface and a sustainable approach to fish preservation, this research sheds light on the mutually beneficial link between IoT technology and solar drying techniques. The results highlight the potential for incorporating smart technologies into food drying systems to address food processing and agricultural industry issues.

Keywords: IoT; Solar Dryer; Effective Fish Drying; Sensor; Swamp Barb

1. Introduction

Bangladesh and other countries consume a lot of fish as food. Fish is popular since it has a lot of health benefits. The issue that comes up most frequently is the drying process of fish. Currently, drying fish by hand requires a lot of time; if sunlight is used, drying fish might take up to 4 to 7 days before the water content reaches 10%. The oldest known technique for drying agricultural products is called "sun drying," which entails just spreading the goods out in the open to dry. This has a number of drawbacks because agricultural products are arranged outdoors and are more susceptible to deterioration from insects and unfavorable weather. A solar dryer is a device that is used to dry materials, primarily food items. There are three categories of solar drying techniques: direct, indirect, and open-sun drying. Since open-sun drying is the least expensive preservation method, it is the most widely used. Nevertheless, there are a number of disadvantages to this method, including weather instability, a wide application area, a lengthy process, a low rate of drying, a high labor cost, insect, microbial, and avian attack, as well as dust and foreign material mixing. However, most of the disadvantages of open-sun drying are mitigated with solar dryers. They improve the physical characteristics of dried fish while also having a faster and shorter drying period. Using conditional logic to develop an autonomous fish drying apparatus and IoT-based monitoring are two approaches to addressing the issue. The challenge of managing variations in temperature and humidity that occur during the transition phase is characterized by the temperature and humidity control system in fish dryers. A DHT22 sensor, light sensor, and Arduino nano microcontroller is required as system inputs to realize the conditional logic on automatic temperature and humidity regulation in fish dryers. These

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components are also required to program the conditional system. Fish drying conditions can be managed with an Internet of Things (IoT)-based monitoring system for temperature, humidity, and weather. The system is successful in accordance with design, as evidenced by the experiments conducted on system testing and comparison with the temperature/humidity meter. The relative error rate of the temperature system is 1.62%, and the humidity is 1.96%.

Solar dryers are an appropriate food preservation technique for sustainable development, as drying is a great method of food preservation. Even before cooking, drying was most likely the first food preservation technique ever employed by humans [1]. In order to create a product that can be securely stored for an extended amount of time, it entails removing moisture from agricultural produce. Due to biochemical interactions and high moisture content, many agricultural goods are susceptible to microbial and other spoilages. As a result, in order to reduce the product's moisture content, drying or dehydration procedures must be performed. The purpose of drying food is to prevent microbiological development and biochemical reactions by removing water from it. Drying extends the product's shelf life and makes it more accessible during off-peak times. [2]

The idea of utilizing solar energy to generate high temperatures has been around since the classical era. Since the dawn of time, people have used solar radiation for residential, agricultural, and personal purposes. The literature about Archimedes' 18th-century research on the dispersal of the sun's rays using flat mirrors contains reports of Antoine Lavoisier's solar furnace and Joseph Priestly's use of solar rays using the telescope. A sun distillation facility that produced 22712.47 liters of seawater per day over 40 years of operation on 4750 square meters of land was developed in the 19th century. John Ericson's technique for converting solar energy into mechanical energy has also been released. it produces 1 horsepower (746 W) for every 9.3 square meters of surface collected [3]. Modern studies on the usage of solar energy started to be conducted in the 20th century. Small-scale steam engines, solar batteries, and other innovations have been made, but it is challenging to sell them due to competition from engines that use inexpensive fuel. The United States began making efforts to make solar energy a practical source of energy in the middle of the 1970s as a result of oil and gas shortages, rising fossil fuel prices, and the depletion of other resources. Solar dryers provide greater temperatures, lower relative humidity, lower product moisture content, and less spoilage throughout the drying process, in contrast to natural "sun drying," which renewed interest. Another safer method of using solar energy for power generation, heating and cooling, and other purposes is sun drying. [4] Solar dryer is about 8-12% more efficient than open sun drying. [5]. SBD-dried paddy had a higher average germination rate (89.66%) than sun-dried paddy (84%). For SBD-dried paddy, the milling recovery was 71%, while for sun-dried paddy, it was 72.4%. [6]. For paddy drying, the STR dryer's drying temperature ranged from 38°C to 42°C. The STR dryer's drying and heat-conveying efficiency were determined to be approximately 31.2% and 19.91%, respectively. [7]

So the objectives for this research are

- To develop a user-friendly IoT interface for monitoring and controlling fish drying process.
- To evaluate the efficiency of fish drying by solar dryer using IoT technology.
- To evaluate the performance of a box solar dryer with open sun drying.

2. Material and methods

Careful consideration is needed to select appropriate methods, procedures, and equipment for designing the solar dryer. This chapter briefly describes the methods and techniques.

2.1. System Requirements

Table 1 System Requirements

Hardware Requirements		Software Requirements
Plywood	LCD display	C++
4mm transparent glass	Breadboard	Arduino IDE
Solar panel	Jumper wire	Laptop
Stainless steel	DHT-22	
Paint	LUX sensor	
Thermal Sheets	Bulb	
Aluminum foil sheet	Battery	
12V exhaust fan	Inverter	

Arduino Uno Relay	Solar charge controller	

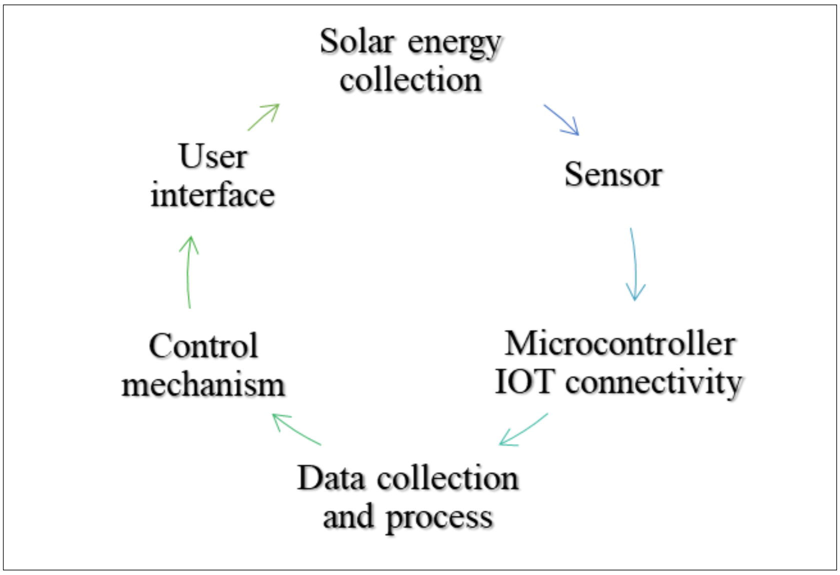

Figure 1 System flow

2.2. System Flow

The system flow (Fig. 1) gives an overview of the system. It takes advantage of solar energy that gets through the glass. To absorb more energy, the interior of the glass was painted black. The dryer's inside air moves about due to the heat. Hot air exits via the top vent and cold air enters through the bottom vent when the vents are open. The air continues to move as a result. The hot air leaving the dryer has more moisture in it than the chilly air entering it while the dryer is not in use. Because the hot air is hotter than the cool air, this occurs. Insulation increases the amount of moisture that hot air absorbs while the dryer is empty.

2.3. Experimental Setup

In this experimental setup for an IoT-based solar dryer, a 12W solar panel was used to generate electricity. The power was stored in a 12V battery to power the exhaust fan, bulb, and LCD via the relay module. The exhaust fan was used to maintain an airflow in the drying chamber. Inside the chamber, there was a DHT-22 sensor to measure the temperature and humidity inside the dryer. The lux sensor was used to measure the light intensity for the setup which was important to turn on the bulb set in the chamber (Fig. 2).

Figure 2 Experimental Setup

The IoT Platform was used to control and monitor the system. The logic was implemented to turn the bulb on when the temperature was below 36°C and light intensity was less than 990lux, and turn it off when the temperature was above 36°C and 990lux. Additionally, code was integrated for the IoT module to send temperature data to the server for monitoring, ensuring the safety of the fish in adverse weather conditions or low sunlight.

2.4. Operation principle

As there were no moving parts in the dryer, it was a passive system. The sun's rays passing through the collector glazing give it energy. The interior surfaces of the collector were painted black, which improved the rays' ability to be captured. The trapped energy heated the air inside the collector. The air circulation that passed through the drying chamber was driven by the greenhouse effect that was created within the collector. When the vents were opened, hot air rises and exits the drying chamber through the upper vent, while ambient temperature air enters the collector through the bottom vent. Hot air at a temperature of "Te" exits through the upper vent and cooler air at a temperature of "Ta" enters through the lower vents, an air current was thus maintained. The incoming air at temperature 'Ta' had relative humidity 'Ha', and the outgoing air at temperature 'Te' had relative humidity 'He' when the dryer was empty of things to be dried. Ha > He since Te > Ta and the dryer was empty. Because of the difference between "Ha" and "He," the hot air that was released from the dryer tends to pick up more moisture. Therefore, the insulation received was principally used in increasing the affinity of the air in the dryer to pick up moisture.

2.5. Control mechanism:

A program (Fig. 3) was written for the microcontroller to read temperature data from the sensor. For any adverse weather conditions or not enough sunlight, we implemented logic to turn the bulb on when the temperature was below 36°C and light intensity less than 990lux and turn it off when the temperature is above 36°C and 990lux. Finally, integrated the code for the IoT module to send temperature data and server for monitoring. It was necessary because fish is very perishable, due to lack of sunlight fish can be spoiled.

```
if (isnan(temperature) || isnan(humidity)) {
  Serial.println(F("SAD!"));
  return;
}

display.clearDisplay();

display.setCursor(12, 12);
display.print(F("Temp: "));
display.print(temperature);
display.print(" *C");
display.setCursor(12, 32);
display.print(F("Humidity: "));
display.print(humidity);
display.print("%");
display.setCursor(12, 52);
display.print(F("LSV: "));
display.print(LSV);

display.display();

if (temperature > 36) {  // Adjust the temperature as
needed
  digitalWrite(RELAY_PIN, LOW);
  digitalWrite(LIGHT_PIN, HIGH);
} else {
  digitalWrite(RELAY_PIN, HIGH);
digitalWrite(LIGHT_PIN, LOW);
}


float h = dht.readHumidity();
float t = dht.readTemperature();
float f = dht.readTemperature(true);

if (isnan(h) || isnan(t) || isnan(f)) {
   Serial.println(F("Failed to read from DHT sen-
sor!"));
  return;
}

float hif = dht.computeHeatIndex(f, h);
float hic = dht.computeHeatIndex(t, h, false);

Serial.print(F(" Humidity: "));
Serial.print(h);
Serial.print(F("%  Temperature: "));
Serial.print(t);
Serial.print(F("°C "));
Serial.print(f);
Serial.print(F("°F  Heat index: "));
Serial.print(hic);
Serial.print(F("°C "));
Serial.print(hif);
Serial.println(F("°F"));


int data = analogRead(ldrPin);
Serial.println("");
Serial.print("Light sensor ");
Serial.print("value: ");
Serial.print(data);

if (data <= threshold) {
  digitalWrite(LIGHT, HIGH);
} else {
  digitalWrite(LIGHT, LOW);
}
delay(500);
}
```

Figure 3 Visual representation of the code

2.6. Circuit Diagram

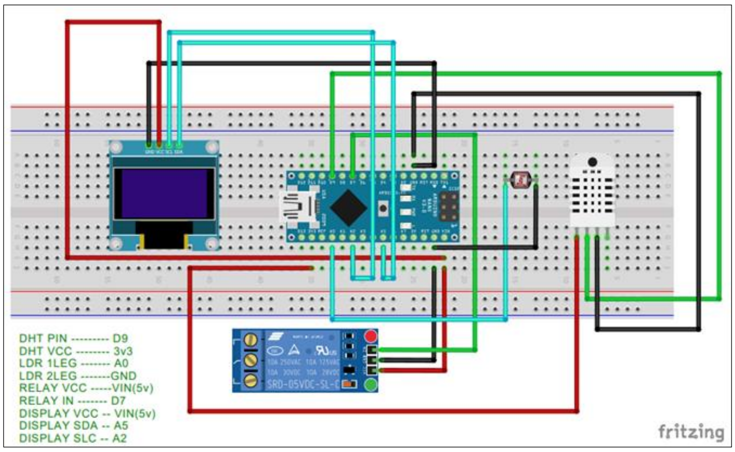

Figure 4 Pictorial view of circuit diagram

2.7. Logic Diagram

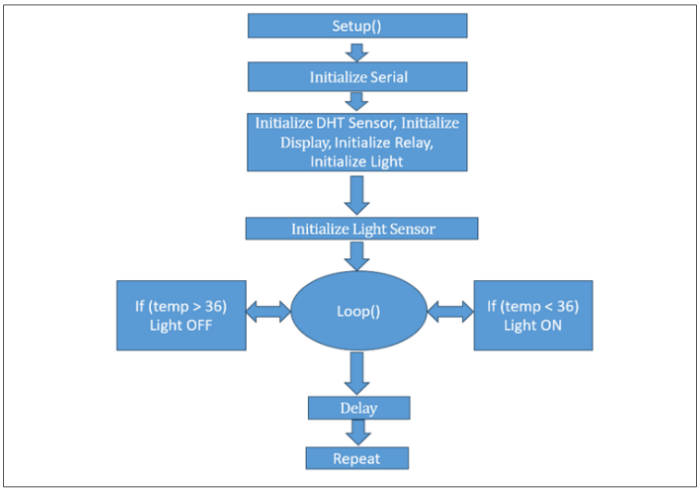

Figure 5 Logic flow diagram

The microcontroller's programming to read temperature data and the logic we used to regulate the light bulb based on temperature and light intensity are depicted in the above image. We also included an Internet of Things module that sends temperature data to a computer for monitoring, which is essential to keep fish from spoiling from a lack of sunshine.

2.8. Volume of the drying chamber

All dimensions are in inches 1 litre = 61.024 in3

Capacity = (18 × 18 × 24)/61.024

=127.425 liters

2.9. Data collection

The experiments were conducted in the month of October for *Swamp Barb* from 10 am to 5 pm daily in 2023, the dryer was placed outside with the collector facing the sun at the rooftop of the faculty building. The collector has been rigidly fixed to the dryer by nut and bolt at an angle of 34.89° to the horizontal to obtain an approximately perpendicular beam of sun rays. The first day was used for evaluating the dryer's performance when loaded with fresh fish. The sample was measured using a balance and 910 grams of fish divided equally into two parts were used for drying. One part of the sample was placed inside the drying chamber and the other part was placed under direct sunlight. The temperature and humidity of the air in the drying chamber by the IoT-based user interface and the atmosphere were measured using a temperature-humiditydigital hygrometer. Temperature and humidity readings were taken at equal intervals from 10 am to 5 pm. Light intensity reading was obtained by Lux sensor at the same intervals for both products.

2.10. Data Analysis

Where,

DC = Drying capacity, (ton/hr) W_t = Weight of total grain, ton, t = Recorded time (hr)

Energy consumption, $E_i = \frac{Rs*A*t}{10^{\wedge}6}$

Drying efficiency, $\dot{\eta} = \frac{W*L}{Et}$

- % of total moisture content loss for fish = $\frac{initial\ mass - final\ mass}{initial\ mass} \times 100$ (Wet basis)

- Drying rate per hour for fish = $\frac{total\ weight\ of\ water\ removed\ after\ a\ time}{total\ period\ of\ drying}$
- Drying Capacity, DC=$\frac{Wt}{t}$

3. Results and discussion

3.1. Experiment on Day-01

3.1.1. Hourly variation of temperatures in the collector, drying chamber compared with the ambient temperature of Fish:

Table 1 Hourly ambient air, drying chamber, and collector temperature of Swamp Barb

Time	Ambient Temperature	Outlet Temperature	Drying Chamber Temperature
10:00 AM	34	54	39
11:00 AM	33.9	46.8	37.4
12:00 AM	39.1	60.4	43.1
1:00 PM	40	68	51
2:00 PM	36.7	53	42.3
3:00 PM	37.8	50.8	42
4:00 PM	31.1	44.1	38.7
5:00 AM	30.2	37.2	36.7

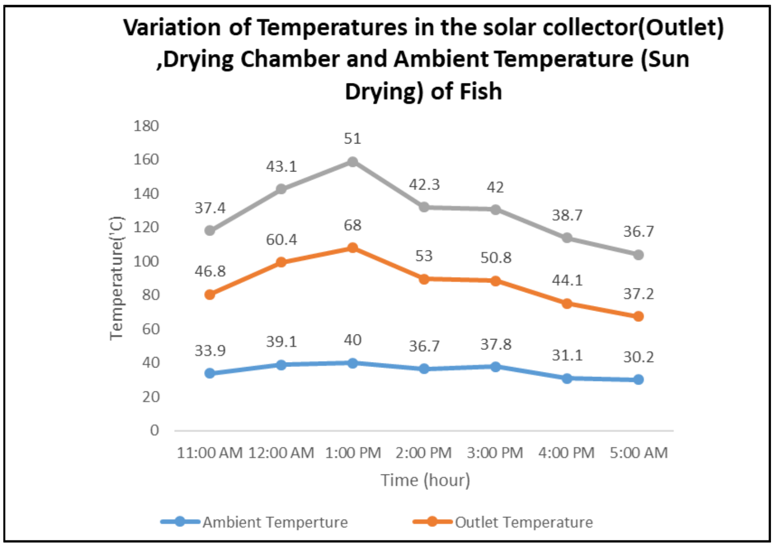

Figure 6 Variation of Temperatures in the Solar Collector (Outlet), Drying Chamber, and Ambient Temperature (Sun Drying) of Fish

The results of the hourly variation of the temperatures in the drying chamber and solar collector compared with the ambient temperature are shown in Table 2 and Figure 6 after a day. At 10 am the temperature of the ambient (atmosphere), outlet (collector), and drying chamber respectively 34°C, 54 ∘ C, and 39°C. From 10 am to 1 pm, the temperature increases gradually. The temperature inside the drying chamber was found to be highest at 51° C at 1 pm compared with ambient. As we see from the above chart the temperature normally increases with time and reaches the peak point during the most daylight hours at 1 pm. Then after 1 pm, the temperature decreased simultaneously as the solar radiation depleted, and at 5 pm the temperatures of ambient (atmosphere), outlet(collector), and drying chamber were 30.2° C, 37.2° C, and 36.7° C.

3.1.2. Hourly Variation of Relative Humidity of the Ambient Air and Drying Chamber

The relative humidity percentages of the drying chamber and the ambient air were observed and the results are given in Table 2 and Figure 7 after a day of drying for fish (Swamp barb).

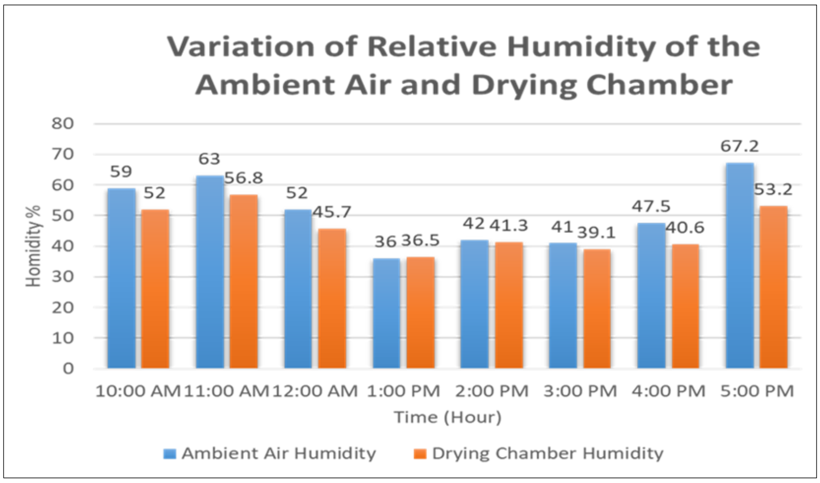

Figure 7 Variation of Relative Humidity of the Ambient Air and Drying Chamber

The relative humidity percentage in the drying chamber was less than equal to the ambient humidity percentage at 10 am. Still, the humidity percentage declined sharply up to 1 pm in the drying chamber compared to the ambient humidity. The lowest humidity inside the drying chamber was also recorded at 36.5% at 1 pm. Higher temperatures and lower humidity favor better drying without much color change. After 1 pm the humidity both for the drying chamber and the air increased, but in the drying chamber, it was quite small as the chamber is fully enclosed and inside the chamber, a high- temperature was operated compared with ambient temperature.

3.1.3. Variation of Average Light Intensity with Time

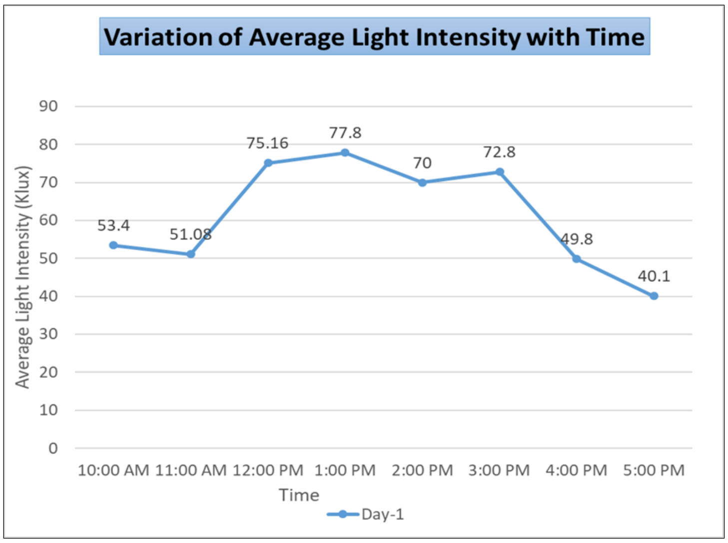

Figure 8 Variation of Average Light Intensity with Time

The light intensity was measured by a lux sensor. The intensity was recorded by observing the solar radiation at the site where the dryer was set up. The light intensity variation for cabbage drying is shown in Figure 8. The average light intensities were found to be highest at 77.8 Klux during the most daylight hours at 1 pm, and after that, it was observed to decline continuously. The lowest light intensity was measured at 40.1K lux at 5 pm as the intensity of light at that time was minimal. From 12 am to 3 pm, the intensity of light was maximum. From the above line diagram, we see that the light intensity was very high all day long. The sky was not cloudy that day.

3.2. Experiment on Day-02

3.2.1. Hourly ambient air, drying chamber, and collector temperature of Swamp Barb

The data of hourly variation of the temperatures in the drying chamber and solar collector compared with the ambient temperature are shown in Figure 9 after 2nd day of daying. From 10 am to 12 am the temperature increases and at 10 am the temperatures for ambient, drying chamber and collector were 31.9 ∘ C, 38.4 ∘ C, and 50.6 ∘ C. The temperature inside the drying chamber was found to be highest at 51.8 ∘ C at 11 am compared with ambient and collector(outlet) 42.2 ∘ C and 77.3 ∘ C. As we see from the above chart the temperature gradually increases with time and reaches the peak point during the most daylight hours at 11 am. Then after 11 am, the temperature decreased simultaneously as the solar radiation depleted, and at 5 pm the temperatures were 30.1 ∘ C, 31.7 ∘ C, and 33.1 ∘ C for ambient, drying chamber, and collector (outlet).

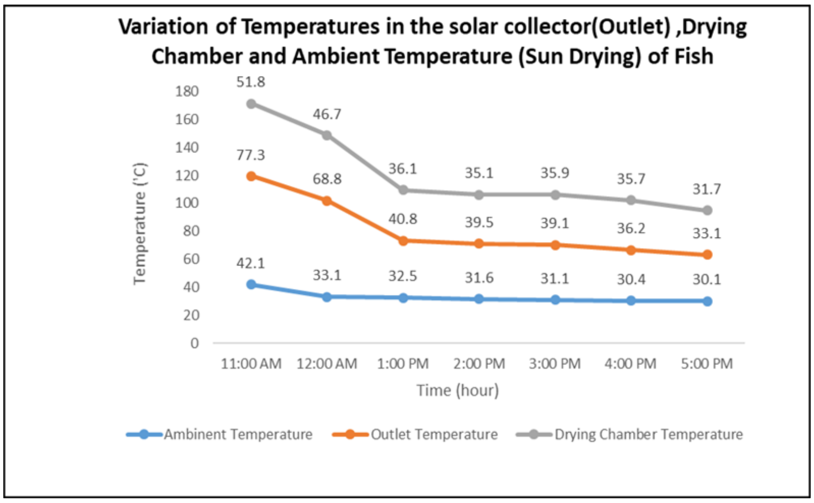

Figure 9 Variation of Temperatures in the solar collector(Outlet), Drying Chamber, and Ambient Temperature (Sun Drying) of Fish

3.2.2. Hourly Variation of Relative Humidity of the Ambient Air and Drying Chamber

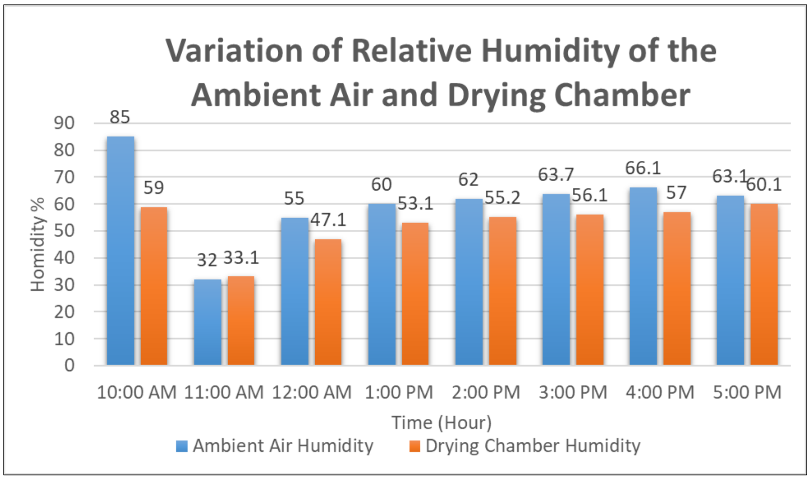

Figure 10 Variation of Relative Humidity of the Ambient Air and Drying Chamber

The relative humidity percentage of the drying chamber and the ambient air were observed and the data are given in Figure 10 after a day of drying for carrots. The relative humidity percentages at 10 am in the drying chamber and ambient air were 59% and 85%. Still, the humidity percentage declines sharply up to 11 am in the drying chamber compared to the ambient humidity. The lowest humidity inside the drying chamber was also recorded at 32% during the most daylight hours at 11 am. Higher temperatures and lower humidity favor better drying without damaging the crops. After 11 am the humidity both for the drying chamber and ambient air increased, but in the drying chamber, it was quite small as the chamber is fully enclosed and inside the chamber, high temperature was observed compared with ambient temperature. At 5 pm the humidity in the drying chamber was found to be 60% whereas in the air it was 63.1%.

3.2.3. Variation of temperature With Average Light Intensity

The light intensity was measured by a lux sensor. The intensity was recorded by observing the solar radiation at the site where the dryer was set up. The light intensity variations are shown in Figure 11 for fish (Puti fish) after 2nd day of drying. The average light intensities were found to be highest at 66.9 Klux during the most daylight hours at 11 am and after that, it was found to decline continuously in figure 4.11. The lowest light intensity was measured at 39.8 Klux at 5 pm. From the above line diagram, we see that the light intensity was very high all day long. The sky was not cloudy that day.

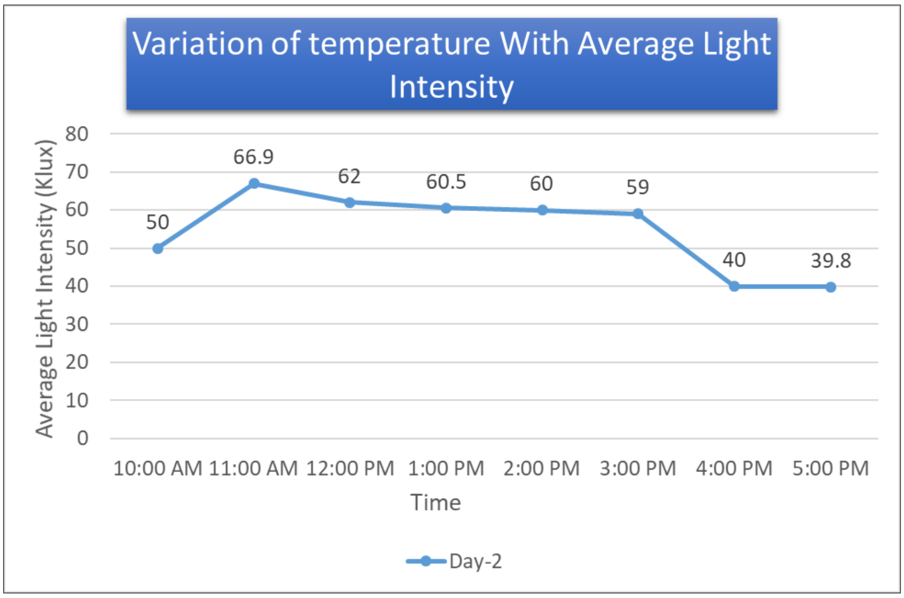

Figure 11 Variation of temperature With Average Light Intensity

3.3. Experiment on Day-03

3.3.1. Variation of Temperatures in the solar collector (Outlet), Drying Chamber, and Ambient Temperature (Sun Drying) of Fish

The results of the hourly variation of the temperatures in the drying chamber and solarcollector compared with the ambient temperature are shown in Figure 12 after 3rd day of drying for fish (Puti). At 10 am the temperatures for ambient, drying chamber, and collector(outlet) were 32.2 ∘ C, 40.1 ∘ C, and 58.2 ∘ C. The temperature inside the drying chamber was found to be highest at 54.8 ∘ C at 1 pm compared with ambient. As we see from the above chart the temperature normally increases with time and reaches the peak point during the most daylight hours at 1 pm. Then after 1 pm, the temperature decreased simultaneously as the solar radiation depleted, and at 5 pm the temperatures were 31.2 ∘ C, 45.9 ∘ C, and 51.2 ∘ C for ambient, drying chamber, and collector (outlet).

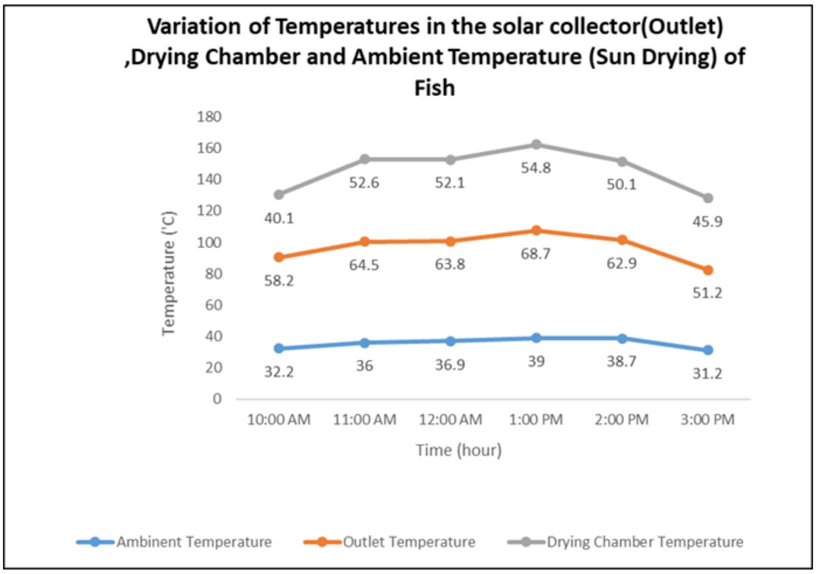

Figure 12 Variation of Temperatures in the solar collector(Outlet) , Drying Chamber, and Ambient Temperature (Sun Drying) of Fish

3.3.2. Hourly Variation of Relative Humidity of the Ambient Air and Drying Chamber

The relative humidity percentages of the drying chamber and the ambient air were observed and the results are given in Figure 13 after 3rd day of drying for puti fish. The relative humidity percentage in the drying chamber was far equal to the ambient humidity percentage at 10 am and it was respectively 78.3% and 52.9%. The lowest humidity inside the drying chamber was also recorded at 26.3% at 1 pm. Higher temperatures and lower humidity favor better drying without much color change. After 1 pm the humidity both for the drying chamber and the air increased, but in the drying chamber, it was quite small as the chamber is fully enclosed, and inside the chamber, a high temperature was operated compared with ambient temperature.

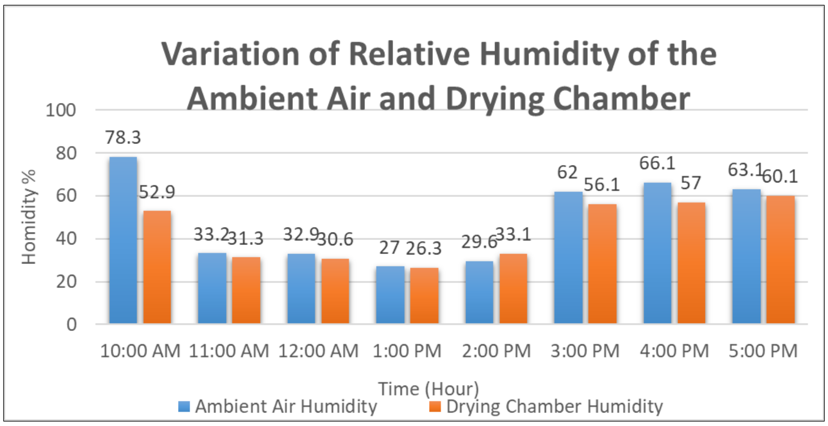

Figure 13 Variation of Relative Humidity of the Ambient Air and Drying Chamber

3.3.3. Variation of Average Light Intensity with Time

The light intensity was measured by a lux sensor. The intensity was recorded due to observing the solar radiation in the site where the dryer was set up. The light intensity variations are shown in Figure 14 for fish after 3rd day of drying. The average light intensities were found highest at 75 Klux during the most daylight hours at 1 pm and after that, it was found to decline continuously in the figure. The lowest light intensity was measured at 49.2 Klux at 5 am. That day was also shiny.

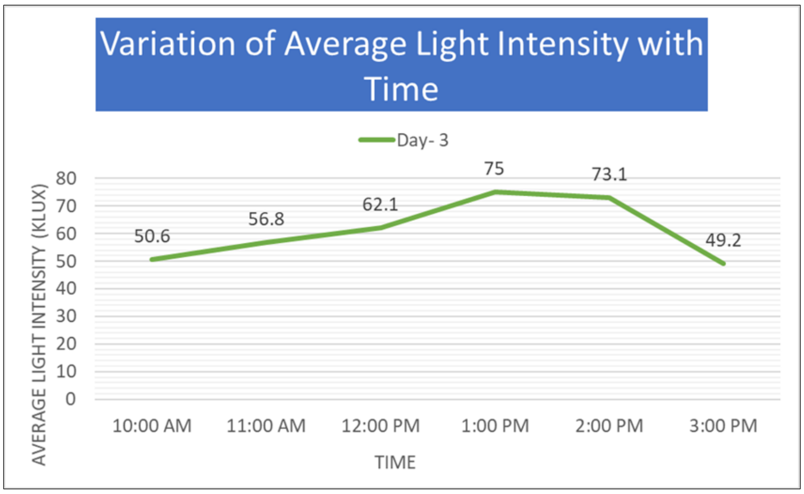

Figure14 Variation of Average Light Intensity with Time

3.4. Percentage of total moisture loss and average drying rate for fish

The % of total moisture loss in fish after 22 hours in the drying chamber was found to peak at 85% compared to the sun drying at 67% (Figure 15). The Average drying rate per hour for IoT-based solar dryers was 14.77 gm/hr compared with sun-dried fish at 11.64 gm/hr (Figure 16).

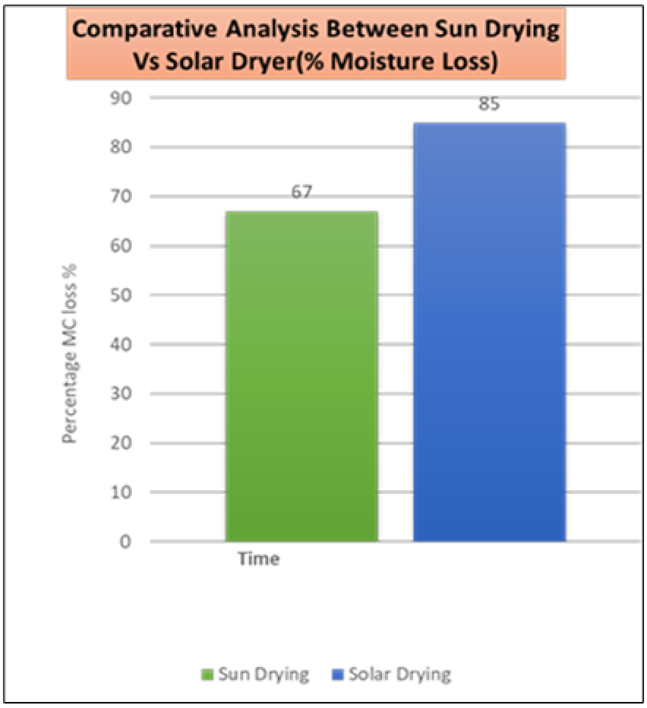

Figure 15 Comparative analysis between sun drying Vs solar dryer (% Moisture Loss)

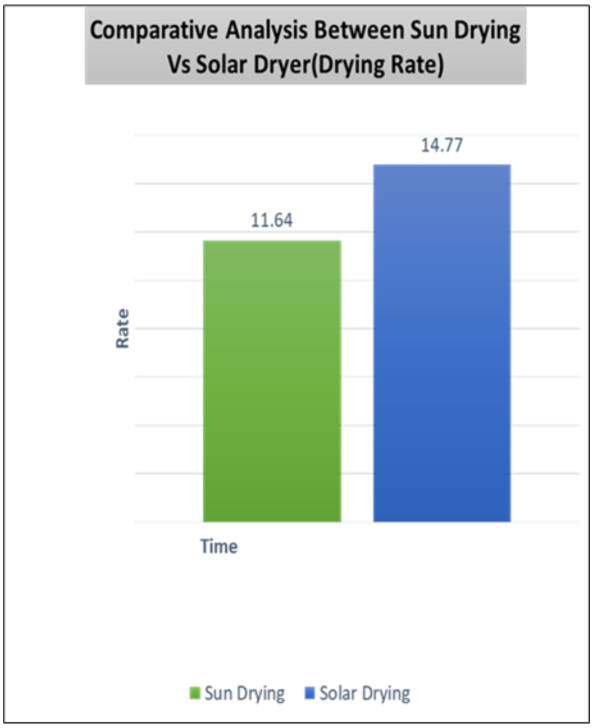

Figure 16 Comparative analysis between sun drying Vs solar dryer (Drying Rate)

4. Conclusion

Though the high initial costs of solar drying systems provide a substantial barrier to their adoption, especially considering the low income level of rural populations in developing nations. However, using inexpensive and recyclable parts to build these systems benefits farmers greatly because it produces more high-quality food with less waste.This paper presents the modification and performance evaluation of Iot enabled solar dryer compared with open sun drying. From this studies, it found that the % of total moisture loss in fish after 22 hours in the drying chamber was found to peak at 85% compare to the sun drying of 67% .The Average drying rate per hour for IoT based solar dryer was 14.77 gm/hr compared with sun dried fish 11.64 gm/hr. The iot-based sun drier can speed up crop drying by raising the outside air temperature noticeably. The product within the dryer takes less attention when compared to drying outside in the elements, such as when it rains or is attacked by insects (both human and animal). Compared to a mechanical dryer, the capital cost of building a solar dryer is far lower. A considerably higher ambient air temperature may be achieved using the IoT-based solar dryer, which elevates the drying process of crops. This kind of solar dryer is thought to help underprivileged farmers secure a sustainable life because dried food sales have increased.

The study's conclusion, in summary, is that small retailers and farmers can utilize an iot-based solar dryer as an affordable method of drying fish. Furthermore, supporting the idea that Iot enabled solar drying is preferable for the high drying rate, high percentage of removed moisture content, and superior quality in the iot enabled solar-dried samples as against the sun-dried samples. Apart from that, an intuitive interface is provided by IoT-enabled sun drying to oversee and manage the fish drying procedure. The goal of this type of IoT-enabled solar dryer is to help poor farmers establish a stable source of revenue over the long run and pave the path for processing sustainable agriculture

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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