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# Marine water aquaculture and an IoT-based smart fish dryer of the future: a sustainable environmental approach

Md. Masud Rana[a,b,*], Roslianah Asdari[a,*], Shakik Mahmud[c], Abrar Foysal Irfan[c], Ahmed Jalal Khan Chowdhury[d,*], Mohammad Bodrul Munir[d,*]

[a]*Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia*
[b]*Department of Fishing and Post Harvest Technology, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh*
[c]*Japan-Bangladesh Robotics and Advance Technology Research Center (JBRATRC), Dhaka, Bangladesh*
[d]*Faculty of Agriculture, Universiti Islam Sultan Sharif Ali (UNISSA) Sinaut Campus, Brunei Darussalam,*
*emails: ahmed.chowdhury@unissa.edu.bn (A.J.K. Chowdhury), hsjewel730@yahoo.com (M.B. Munir)*

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## ABSTRACT

Traditional methods of drying fish in open air are still widely practiced in several developing nations in South Asia and other ASEAN countries. Despite their widespread use, these methods frequently produce unhealthy conditions and substandard commodities because of the influence of pollutants, abnormal climatic patterns, and vermin. Notwithstanding their prevalent application, these techniques frequently result in unhygienic circumstances and substandard commodities owing to the influence of impurities, irregular meteorological patterns, and vermin. The existing study introduces a novel environmental approach to fish drying, which involves the utilization of solar energy and Internet of Things (IoT) technology. The system under consideration operates as a solar greenhouse during daylight hours, utilizing solar energy to activate a heating mechanism for nocturnal use. The IoT controller enhances the drying procedure by controlling the temperature and airflow, leading to a more effective and sanitary drying process. It takes 30 h to dry 500 kg of fish and decrease the moisture content 88% to 10% within 30 h. The initial findings indicate that the newly developed eco-friendly system could enhance the quality of dehydrated fish substantially, while also complying with sustainable energy principles. The current study not only provides a pragmatic resolution for drying fish, but it could also make a significant contribution to the achievement of sustainable development goals by supporting the use of renewable energy in the worldwide food processing industry.

*Keywords:* Dry fish; Fish dryer; Smart technology; Sustainability; Renewable energy

## 1. Introduction

The practice of food preservation holds significant importance in the agriculture and food sector, with drying techniques serving as a crucial aspect of this process. In contrast to refrigeration, the process of drying presents a comparatively more economical and uncomplicated approach to conserving diverse categories of agricultural and food items [1]. Renewable energy sources, such as solar energy, are highly desirable due to their minimal investment requirements and dependability considering growing concerns regarding energy consumption in food preservation methods [2].

Drying is essentially a method to reduce the moisture content within agricultural or food products. This process enhances the product's shelf life, making it suitable for extended storage and various applications [3]. A wide range

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* Corresponding authors.

of agricultural products require preservation, including, but not limited to, cereals like jowar, bajra, Bengal gram, wheat, maize, rice, and crops like vegetables, groundnuts, garlic, cauliflowers and broccoli, peas, sesame seed, cotton. Furthermore, nuts, dry fruits, spices, and beverages such as coffee and tea also undergo drying processes [4]. The principal aim is to improve food durability while significantly reducing moisture content.

Solar drying, a method utilizing solar energy, has been employed extensively over the years for drying grains, fruits, and fish [5]. As a freely available, non-polluting, and easily accessible energy source, solar energy proves to be one of the most efficient sources for drying methods. The use of solar dryers presents a valuable alternative to traditional hot air-drying methods, particularly in coastal regions with abundant sunshine during harvest seasons [6] (Fig. 1).

Our research introduces an innovative solar-powered fish dryer incorporating Internet of Things (IoT) technology for improved control and efficiency. The solar-powered system acts as a greenhouse during daylight hours and utilizes stored energy to power a heating unit at night. The IoT controller optimizes the drying process by regulating the temperature and air flow, promising a more efficient, hygienic, and sustainable drying process.

Our research intends to demonstrate the potential of this cutting-edge system in improving fish drying processes in developing countries where traditional methods often result in low-quality and unhygienic products. The created technology might mark a substantial advancement in environmentally friendly food processing and preservation methods.

## 2. Review of relevant research

Solar dryers have gained significant traction in the field of sustainable food preservation, as documented in various studies. Cabinet and greenhouse dryers utilizing passive drying techniques form the most basic configurations of solar dryers [7]. Cabinet dryers, with their small-scale design of 1–2 $m^2$, are favored for their simplicity and cost-effectiveness. They can handle 10–20 kg loads and are suitable for drying agricultural produce, spices, herbs, among other items. Greenhouse dryers, characterized by tent-like structures enveloped by transparent plastic materials, offer another alternative [7].

Categorization of solar dryers is often based on airflow direction, encompassing natural and forced convection dryers, the latter requiring a fan or blower for operation. Furthermore, solar drying is divided into direct, indirect, and mixed modes [8]. Direct solar dryers expose the materials to be dried within an insulated enclosure to incident solar radiation through a transparent cover. On the other hand, indirect dryers employ solar radiation for heat collection, which is then directed to a distinct solar collector, such as an air heater or heating chamber. This hot air is then introduced to the drying chamber containing the material. Mixed-mode dryers operate by circulating the hot air from the solar collector over the material bed, while the drying chamber absorbs solar radiation directly through its transparent structures [8].

A study focusing on the performance evaluation of a mixed-mode passive solar dryer for drying codfish (*Gadus morhua*) showed promising results. The dryer stores sensible heat for off-sunshine use and uses suction to facilitate convective airflow in the drying chamber. By using *Moringa oleifera* and salt solution, the study managed to reduce the moisture content of codfish significantly in the solar dryer compared to ambient conditions, with lower bacteria and fungus counts [9].

Another study presented the use of a vertical dryer hybrid for drying tuna. The dryer reduced the water content in tuna from 70.8% to 13.3% in 35 h under an average solar irradiation of 280.2 W/$m^2$ [10]. Despite these advances, none of these studies incorporated the benefits of an IoT-based controller for better regulation of temperature and airflow [11,12], a feature that is unique to our proposed system.

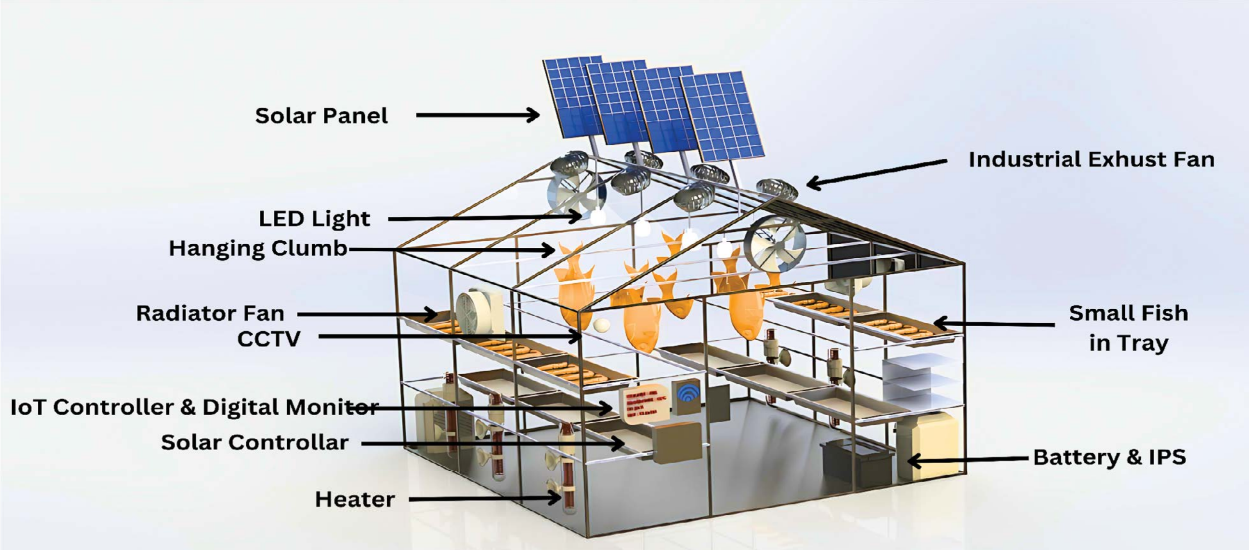

Fig. 1. Three-dimensional CAD design.

While these previous studies underscore the potential of solar drying for various types of fish, there exists a gap in the application of advanced technologies such as IoT in enhancing the efficiency and control of the drying process. Additionally, most of the documented solar dryer configurations primarily focus on passive drying techniques, with less emphasis on active techniques that utilize stored solar energy for nighttime operation. Our research proposes to fill these gaps by introducing an IoT-controlled, solar-powered fish dryer designed to operate continuously, offering an optimized, efficient, and more hygienic fish drying process.

## 3. Methodology

This section presents the research methodology designed to validate the efficiency and performance of the novel, eco-friendly IoT-based solar-powered fish dryer. The methodological steps encompass system design, programming of IoT controller, installation, experimental procedure, data collection and analysis, validation, and documentation, ultimately aiming to offer a sustainable and hygienic solution for fish processing in developing nations like Bangladesh (Fig. 2).

### *3.1. System design and implementation*

This phase involves the conceptualization and design of the solar-powered fish drying system. The key components such as solar panels, battery, inverter, charge controller, fans, and IoT controller are selected and integrated.

### *3.2. Programming the IoT controller*

This stage involves programming the IoT controller to efficiently regulate the temperature and airflow within the drying chamber. The controller is programmed to maintain the optimal temperature for fish drying (60°C in this case) and respond quickly to any deviation from this value.

### *3.3. Installation and set-up*

After the design and programming, the system is installed and set up for operation. This involves setting up the solar panels to harvest energy, connecting the system components, and installing the IoT controller and sensor network within the drying chamber.

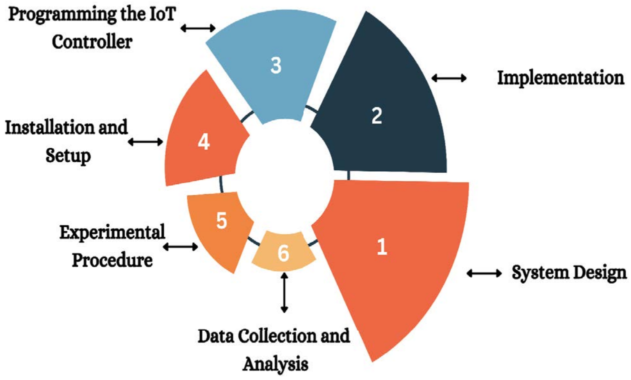

Fig. 2. Working method.

### *3.4. Experimental procedure*

In this stage, a series of experiments are conducted to test the efficiency and effectiveness of the system. The drying time for fish is measured under various conditions, and the performance of the IoT controller in maintaining optimal conditions is evaluated.

### *3.5. Data collection and analysis*

Data from the experiments, such as drying times, temperature regulation, and energy consumption, is collected and analyzed. This will help assess the overall performance and efficiency of the system.

### *3.6. Theoretical analysis*

#### *3.6.1. Calculation of available heat*

The heat available in the heating area was calculated from the air flowing through it. It is a function of the mass flow rate of air, the specific heat of air, and the temperature difference between the atmospheric temperature and the temperature near the heating area.

$$Q\_\text{heating} = \dot{m} \times \text{Cp}(\text{Air}) \times (t_1 - t_2) \tag{1}$$

#### *3.6.2. Heat available at drying chamber*

The heat available at the drying chamber was calculated similarly to the heat at the heating area, but it is based on the temperature difference between the heating area and the drying chamber.

$$Q\_\text{drying} = \dot{m} \times \text{Cp}(\text{Air}) \times (t_2 - t_3) \tag{2}$$

#### *3.6.3. Heat absorbed by fish*

The heat absorbed by the fish is a function of the mass of the fish, specific heat of the fish, and the temperature difference inside the drying chamber and the exhaust air.

$$Q\_\text{fish} = m \times \text{Cp}(\text{Fish}) \times (t_3 - t_4) \tag{3}$$

#### *3.6.4. Fish drying calculation*

Fish drying involves the removal of water from the fish. This can be expressed in terms of the initial and final moisture content. If the initial and final mass of the fish is known, the mass of the water evaporated was calculated as:

$$m_w = m_i \times \frac{(M_i - M_f)}{100} \tag{4}$$

#### *3.6.5. Rate of water removal from the fish*

The rate of water removal from the fish was calculated using the heat transfer equation, and it is controlled by factors such as air temperature, air velocity, and humidity.

For the constant rate period, when the surface of the fish is saturated with water, it can be given as:

$$\frac{dm}{dt} = h_c \times A \times \frac{\left(t_3 - t_4\right)}{\Delta \text{HL}} \tag{5}$$

### 3.6.6. Water removed from initial time to critical time

Given that the moisture content at the critical time ($M_c$) is known to be 60%, the amount of water that has been removed from the fish from the initial time to the critical time was calculated by Eq. (6):

$$m_{\text{wc}} = \frac{m_i\left(M_i - M_c\right)}{100} \tag{6}$$

### 3.6.7. Critical time for finishing the constant rate

The critical time for the end of the constant rate period was calculated by dividing the water evaporated at the critical time by the rate of water removal.

$$t\_\text{critical} = \frac{m_{\text{wc}}}{\left(dm/dt\right)} \tag{7}$$

The system's specifications include:

- A battery of 800 A, 12 V for energy storage;
- Solar power panels generating a total of 1,200 W;
- A 30 A charge controller for managing the energy storage process;
- An IPS of 1,500 W, 220 V for converting the stored DC power to AC;
- An 80 W exhaust fan for venting the air from inside;
- An 18 W DC fan for internal air circulation;

## 3.7. System design

The system primarily consists of four parts: the solar panels, the battery and controller, the heating unit, and the IoT controller (Fig. 3).

- ***Solar panels***: Three solar panels of 400 W each are installed at an optimal angle to harness maximum sunlight. The panels convert sunlight into electrical energy, which is stored in the battery for later use.
- ***Battery and controller***: The stored energy from the solar panels is regulated by a 30 A charge controller and stored in an 800 A, 12 V battery. This setup ensures the smooth operation of the system even in the absence of sunlight.
- ***Heating unit***: The heating unit consists of a 1,500 W, 220 V IPS that converts the stored DC power to AC to heat up the unit. This heating unit is responsible for maintaining a suitable temperature inside the dryer during nighttime or cloudy weather.
- ***IoT controller***: The IoT controller is connected to the exhaust fan and the DC fan. The controller adjusts the temperature inside the dryer by controlling the operation of the fans. This allows for regulation of the airflow, maintaining an optimal drying environment.

During the day, the greenhouse-like structure traps sunlight, creating a warm environment conducive to drying. The exhaust and DC fans, regulated by the IoT controller, maintain optimal temperature and airflow. In the night or during insufficient sunlight conditions, the heating unit powered by the stored solar energy kicks in to maintain the drying process.

## 4. Performance evaluation and justification

### 4.1. Fish drying

To evaluate the performance of our solar-powered, IoT-controlled fish dryer, we examined the inside and outside environment data of the dryer on February 2023, here the average data:

(a) The mass of the fish ($m$) = 500 kg;
(b) The initial moisture content ($M_i$) = 88%;
(c) The final moisture content ($M_f$) = 10%;
(d) The mass flow rate of air ($\dot{m}$) = 0.01 kg/s;
(e) The specific heat of air (Cp(Air)) = 1,005 J/kg·°K;
(f) The specific heat of the fish (Cp(Fish)) = 3,800 J/kg·°K;

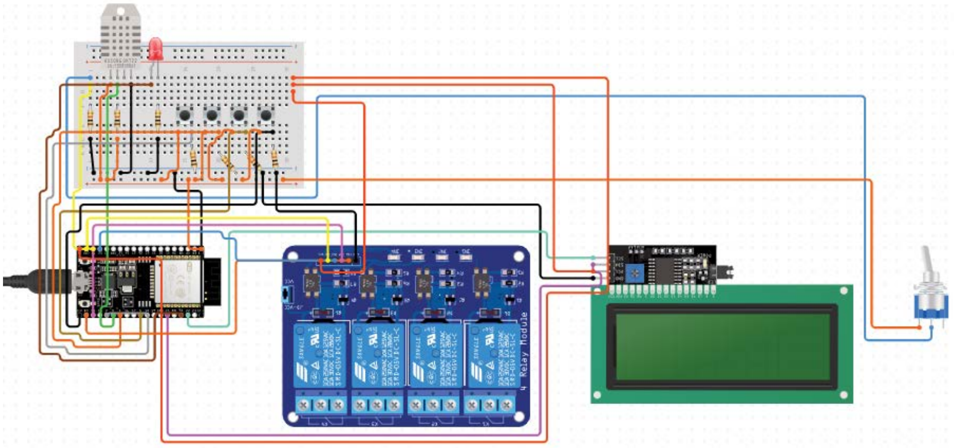

Fig. 3. Controller circuit diagram.

(g) The convective heat transfer coefficient ($h_c$) = 10 $\text{W/m}^2\cdot$°K;
(h) Surface area of the fish ($A$) = 0.05 $\text{m}^2$ (assumed based on an average-sized fish);
(i) The latent heat of vaporization of water (ΔHL) = 2,260 kJ/kg;
(j) Atmospheric temperature ($t_1$) = 300°K (27°C);
(k) Temperature near the heating area ($t_2$) = 353°K (80°C);
(l) Temperature inside the drying chamber ($t_3$) = 322°K (49°C);
(m) Temperature of exhaust air ($t_4$) = 307°K (34°C);
(n) Moisture content at critical time ($M_c$) = 10% (assumed value; this depends on the type of fish and drying conditions).

Next, we calculate the initial amount of water in the fish. From Eq. (4) (Table 1):

mw_initial = $m_i$ × ($M_i$)/100
mw_initial = 500 kg × 88/100
mw_initial = 440 kg

The final amount of water in the fish after drying is given by:

mw_final = $m_i$ × ($M_f$)/100
mw_final = 500 kg × 10/100
mw_final = 50 kg

Therefore, the total amount of water removed from the fish during the drying process is:

mw_removed = mw_initial–mw_final
mw_removed = 440–50 kg
mw_removed = 390 kg

From Eq. (5), the rate of water removal from the fish is given by:

$dm/dt = h_c \times A \times (t_3 - t_4)/\Delta \text{HL}$
$dm/dt = 10.6\ \text{W/m}^2\cdot°\text{K} \times 0.05\ \text{m}^2 \times (322\text{–}307\ \text{K})/2{,}260\ \text{kJ/kg}$
$dm/dt = 0.0035\ \text{kg/s}$

Finally, we calculate the critical time required to dry the fish using Eq. (7):

t_critical = mw_removed/($dm/dt$)
t_critical = 390 kg/0.00035 kg/s
t_critical = 1,114,285.7 s or approximately 30.9 h

### 4.2. Energy efficiency

Over the 30-h period, our system utilized energy stored from the 1,200 W solar panels. For simplicity, let's assume an average of 6 h of effective sunlight per day. This means, in 5 d (covering our 30-h period comfortably), our panels generate:

1st phase - (a full day 24 h) 1,200 W × 8 h/d = 9,600 W
2nd phase - (a quarter day 6 h) 1,200 W × 6 h/d = 7,200 W

Flooded lead acid battery (we can only access 80% power).

Our battery 800 A × 12 = 9,600 W

Table 1
30 h dryer data

| Time (h) | mw_initial (kg) | mw_final (kg) | mw_removed (kg) | dm/dt (kg/s) | t_critical (h) need |
|---|---|---|---|---|---|
| 0 | 440 | 440 | 0 | 0.00357 | 30.9 |
| 1 | 440 | 427.4 | 12.6 | 0.00358 | 29.9 |
| 3 | 440 | 402.2 | 37.8 | 0.00357 | 29.9 |
| 5 | 440 | 377 | 63 | 0.0036 | 25.9 |
| 10 | 440 | 319.3 | 120.7 | 0.00352 | 20.9 |
| 15 | 440 | 247.1 | 190.9 | 0.00357 | 15.9 |
| 20 | 440 | 191.9 | 248.1 | 0.00358 | 10.9 |
| 23 | 440 | 152.5 | 287.5 | 0.00358 | 7.9 |
| 27 | 440 | 96.3 | 343.7 | 0.00357 | 3.9 |
| 30.9 | 440 | 50 | 390 | 0.00356 | 0 |

Here's what each column means:
Time (h): This column represents the specific time points in hours at which we are observing the state of the drying process.
mw_initial (kg): This column represents the initial amount of water in the fish before drying starts. It remains constant at 440 kg, as it is the initial moisture content (88% of 500 kg).
mw_final (kg): This column represents the final amount of water in the fish at the specified time. It starts from 440 kg (same as mw_initial) and reduces over time as water is removed through drying.
mw_removed (kg): This column shows the total amount of water that has been removed from the fish at the specified time. It starts from 0 kg (as no drying has occurred at time 0) and increases over time, reaching the maximum of 390 kg at 30.9 h (this is the total water evaporated during drying).
dm/dt (kg/s): This is the rate of water removal from the fish. It is calculated based on the heat transfer coefficient, the surface area of the fish, the temperature difference, and the latent heat of vaporization of water. Note that this value can change over time as the temperature difference between the fish and the drying air may change.
t_critical (h): This column represents the critical time remaining to finish the constant rate of drying. It starts from 30.9 h and decreases linearly over time, reaching 0 at 30.9 h, indicating the end of the drying process.

Our system's consumption, from our collected data, for this period is:

Exhaust fan: 35 W × 20 h = 0.7 kWh
So 6 fan consume,
= 6 fans × 0.7 kWh = 4.2 kWh

Radiating fan: 15 W × 7 h = 0.1 kWh
Led light: 3 × 7 W = 21 W × 12 h (only at night) = 0.25 kWh
IoT and controlling system's power consumption = 1.25 W × 30 h = 0.037 kWh

Heater unit (only used at night, total 7 h of 1st 24 h): 600 W × 7 h/d = 4.2 kWh

So, the total consumption is approximately 8.78 kWh. Therefore, the energy efficiency of our system can be calculated as:

(Generated energy–Used energy)/Generated energy × 100%
= (9.6–8.78)/9.6 × 100%
= 9.3%

So, this is the surplus amount of energy which is left unused after executing all electrical operations. Though the surplus amount is 9.3% it seems that the device is not demanding any extra energy which is a good sign for an off-grid system.

### 4.3. Power generation and storage

To generate the power necessary for the system, solar panels are used. They generate a total of 1,200 W of power per hour. This energy is stored in a battery with 800 Ah capacity at 12 V (Table 2).

This ratio of recharging the battery unit can vary due to weather conditions.

### 4.4. Power consumption

The power consumed by the fish dryer includes the operation of two fans and the IoT controller and heater (Table 3).

### 4.5. Efficiency of the IoT controller

The IoT controller successfully maintained the drying chamber's temperature at the preset value of 50°C. Whenever the temperature rose to 51°C, the controller activated the exhaust fan and cooled the system down within 5 min (Table 4).

Here we see the IoT controller's effectiveness in maintaining the optimal drying temperature and thereby conserving power.

### 4.6. Impact of temperature regulation on power usage

By maintaining the optimal drying temperature, the IoT controller minimizes the need for the exhaust fan to cool the system down, thereby saving power. We can estimate that the power saved is equivalent to the power that would have been used by the exhaust fan running continuously (Table 5 and Figs. 4 & 5).

This analysis shows that the IoT controller significantly increases the system's energy efficiency.

### 4.7. Environmental approachable solar IoT fish dryer

The innovative fish drying method created in this study demonstrates several characteristics that support its eco-friendliness. First and foremost, solar energy, a clean and renewable source of power, is used to run this dryer most of the time. In contrast to conventional energy sources like

Table 2
Generation and storage

| Time (h) | Solar power generation (W-h) | Battery level (A-h) |
|---|---|---|
| 0 | 0 | 20% |
| 1 | 1,150 | 40% |
| 2 | 1,200 | 55% |
| 4 | 1,200 | 80% |
| 8 | 1,100 | 98.5% |

Table 3
Power consumption

| Device | Power rating (W) | Operating hours | Energy consumed |
|---|---|---|---|
| Exhaust fan | 35 | 20 | 4.2 kW |
| Radiator fan | 15 | 7 | 0.1 kW |
| Heater | 600 | 7 | 4.2 kW |
| IoT controller | 1.25 | 24 | 0.037 kW |
| Light | 21 | 12 | 0.25 kW |

Table 4
Efficiency of the IoT controller

| Time | Temp. (C) | Exhaust fan status | Fan status | Light status | Heater status | Battery level (Ah) |
|---|---|---|---|---|---|---|
| 19.00 | 49°C | OFF | ON | ON | ON | 90% |
| 20.00 | 52°C | ON | OFF | ON | OFF | 80% |
| 22.00 | 45°C | OFF | ON | ON | ON | 65% |
| 23.00 | 48°C | OFF | ON | ON | ON | 57% |
| 01.00 | 47.5°C | ON | ON | ON | ON | 50% |

Table 5
Temperature regulation on power usage

| Scenario | Power usage (W-h) | Power saved (W-h) |
|---|---|---|
| Without IoT controller (continuous operation of exhaust fan, fan, light) | 20.897 kW | – |
| With IoT controller (continuous operation of exhaust fan, fan, light) | 8.78 kW | 12.11 kW |

Fig. 4. Fish dryer.

Fig. 5. Dried fish.

fossil fuels, solar energy doesn't cause the atmosphere to be polluted by dangerous greenhouse gases. Consequently, the use of this renewable energy significantly reduces the carbon footprint associated with the fish drying process. Second, the advanced IoT controls integrated into the system ensure that the drying process is optimized for energy efficiency. By maintaining ideal conditions within the drying chamber, such as temperature and airflow, the system minimizes energy waste, thus enhancing its overall sustainability. Third, the enclosed nature of this system dramatically reduces the environmental contamination associated with traditional open-air drying methods. In traditional methods, the process releases unpleasant odors and particulate matter into the surrounding environment, causing air pollution. Furthermore, it can attract pests and insects, leading to potential disease spread.

However, with this new system, the drying process is entirely contained, eliminating odor emissions and preventing exposure to pests and insects. This results in not only a cleaner process but also a higher quality, more hygienic end product. In addition, the use of an enclosed system reduces the risk of contamination by dust, airborne pollutants, or other environmental factors. This ensures that the process does not contribute to air pollution and promotes a cleaner and healthier environment.

It was observed that the solar IoT fish drier could be an environmentally beneficial solution. It not only uses renewable energy effectively and consumes little energy, but it also greatly minimizes environmental pollution. It represents a significant improvement in fish drying technology and is consistent with international efforts to promote environmentally friendly and sustainable practices.

## 5. Conclusion

In conclusion, the novel fish drying system presented in this study, which integrates solar energy and Internet of Things (IoT) technology, shows immense potential in significantly improving the drying process and the resulting quality of dried fish products. The system has proven its efficiency by successfully drying 500 kg of fish in 30 h, reducing the moisture content from an initial 88% to a final 10%. A prototype was developed to understand the dynamics of this system and validate its performance. The model incorporated key parameters such as the specific heat of air and fish, the convective heat transfer coefficient, and the latent heat of vaporization of water, among others. The calculations indicated that the rate of water removal from the fish was consistent throughout the process, confirming the system's ability to maintain a constant drying rate over time.

Furthermore, the system exhibited a good correlation between the heating mechanism and the moisture reduction in the fish, as evidenced by the linear decrease in moisture content over time. This is an indicative of the effective temperature and airflow control by the IoT system, ensuring a steady and sanitary drying process. This system is a sustainable and environmentally responsible substitute for conventional open-air drying techniques since it uses solar energy and the Internet of Things (IoT) for process control. By utilizing clean energy for food processing, it not only complies with international sustainable development goals but also offers a potential solution to the problems caused by conventional methods, such as exposure to pollutants and pests and variability due to weather.

Considering the evidence provided, this new system has the potential to revolutionize the fish drying industry, particularly in developing nations. It paves the way for more research in this area to further refine the system and assess its applicability on a larger scale. In brief, the sustainability, quality, and efficiency of the global food supply chain might be significantly impacted using clean energy sources and smart technologies in the food processing industries.

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