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Original Article

Design and Development of a Low-Cost Parabolic Type Solar Dryer and its Performance Evaluation in Drying of Kingfish – A Case Study in Oman

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Abstract - *Dry fish is a rich source of proteins and nutrients and can be eaten in many forms. Oman is one of the important fish producers in the world, and there is a high demand for Oman fish in neighboring countries. The Fishery sector is considered an important economic development sector in the Sultanate of Oman. In the fishery sector, the use of technology is not up to the mark because of less awareness of technology applications among Omani fishermen. Also, there is a demand for more cold storage in different regions to store fresh fish, which has not materialized yet. Similarly, there is a demand for perfect and cheap technology in Oman for dry fish to improve the profit of the fishermen. Solar energy is abundantly available in Oman, and there are many possibilities for its use in domestic and industrial applications. Since sunlight is available throughout the year, converting it into thermal or electrical energy is possible. Electricity can be produced by photovoltaic principle (PV) or indirectly with concentrated solar power. Similarly, it is possible to use solar concentrators for many thermal applications. The solar dryer is used to dry fruits, vegetables, leaves, clothes, etc. If any of the items are dried with the help of solar energy, then we can save a lot of non-renewable energy sources and help improve the country's economy. The sun can, at least seasonally at Oman's latitudes, provide a substantial part of the energy needed for various applications. In this work, a solar dryer is proposed to be used to make high-quality dry fish. Using a parabolic concentrator to dry the fish is an effective solution, an innovative idea for the fishermen. The temperature variation in the dryer is directly proportional to the solar intensity. The tracking mechanism combines electronic and mechanical design to track the sun automatically. In this work, a parabolic concentrator with an automatic tracking mechanism was designed, and a performance analysis was done. In the design, copper tubes are used for heat transfer, and then the hot fluid is circulated in the box, which is used to dry the kingfish. As per the experiment, solar collector efficiency obtained from the solar dryer is 77.9%, and the overall efficiency obtained is 33.1 %, and it took three days to dry kingfish of 20kg. There are many advantages in parabolic type solar concentrators related to the quality of dryness in the fish and the time taken to dry the fish, which are elaborately discussed in this paper. This solar dryer technology will improve the green environment, reduce carbon footprint, and save non-renewable sources for the Sultanate of Oman for extended periods.*

Keywords - *Evacuated copper tube absorber, Parabolic solar, Solar energy, Solar dryer, Specific heat.*

1. Introduction

The term energy, familiar in our daily lives, is defined simply as the ability or capacity to do work. Energy is required to sustain and improve quality of life. Energy grows food and keeps people lively. Energy saving is critical in maintaining non-renewable energy sources for the next generations. More of the energy consumption mainly goes for domestic and goods transport. Most energy requirements are met by only petroleum products, not renewable energy sources. Since petrol and diesel resources are reduced worldwide, including in Oman, using this source for all sectors is not easy. So, the use of solar energy is essential in all industries because of its renewable nature and availability all over the world. The primary energy-consuming sectors can be divided into four parts: the agricultural industry, the industrial sector, the transport sector, and the domestic sector. In Oman, most of the energy is consumed in the domestic sector, compared to the other developed countries, like America and Europe, where the consumption is mainly industrial. Overall, the Industrial sector consumes a significant portion of petroleum products. Also, agricultural product prices are going up because of the price hike in petroleum products. It is essential to use solar energy in agriculture, including fishery areas, to reduce the price of food and other related items. This is the main reason for this work, and a cost-effective solar dryer has been designed according to the Oman context. Since the fishery sector is an essential economic contributor in Oman, concrete research is required to store the excess fish thrown away daily due to a lack of technological resources. The research gap in Oman mainly concerns the lack of technological development in the fishery sector. So, this paper addresses the research gap in the technology implementation of drying kingfish using solar energy.

1.1. Energy Crisis in the World

In recent years, we have experienced an energy Crisis in many countries. The energy crisis is due to two reasons,

- The population growth of the world
- Increase in the standard of living of human beings, increasing per capita energy consumption.

Assuming the present energy consumption, it is estimated to be 30 million megawatts by 2030 A.D. However, the present consumption pattern is more than the past, in which the relative energy consumption of countries remains the same, then per capita energy in developed countries remains much more than in developing countries. If the standard of living in developing countries increases, the energy requirement in the world in the year 2030 will be much more than estimated above. If the present trend continues, the world in the future will be more crowded than it is today. Conventional energy sources are developing and may be exhausted by the end or the beginning of the next century. The percentage of use of various sources for total energy consumption in the world is given in Figure 1. While fossil fuels will be the primary thermal power source, many countries fear they will eventually be exhausted in the next century. Therefore, many countries try other systems based on non-conventional and renewable sources. These are solar energy, Wind energy, Geothermal Energy, Nuclear energy, Biomass, Marine energy, Tidal energy, and wave energy.

2. Solar Energy

Solar energy has the most significant potential of all renewable energy sources, and it will be one of the most critical supplies of energy when other sources in the country have depleted. The use of direct power from the sun's radiation has many advantages. Solar power is plentifully available in Oman, even in regions remote from the sources of fossil fuels. It is essentially a non-depletable source of energy in comparison with fossil fuels or nuclear fission power, and it is cost-free in its original radiation form. Of course, there is a significant cost for the capital plant required to convert solar energy to other forms of energy. If solar energy is utilized locally, the need to transport the energy is avoided. Solar power can also be used in small units for individual buildings or homes. Solar devices hold promise for the developing world and the economically developed country. Since solar power burns no fuel, it causes no air or water pollution. The power from the sun intercepted by the Earth is approximately 1.8x1011 MW, which is many times larger than the present consumption rate on Earth of all commercial energy sources. Thus, in principle, solar energy could continue to supply all the world's present and future energy needs. The energy the sun radiates on a bright, sunny day is approximately 1 KW/m2. Attempts have been made to use this energy to raise the stem, which may be used to drive the prime movers to generate electrical energy. The energy can be concentrated in solar furnaces, for example, achieving a temperature of 500 degrees Celsius within an hour.

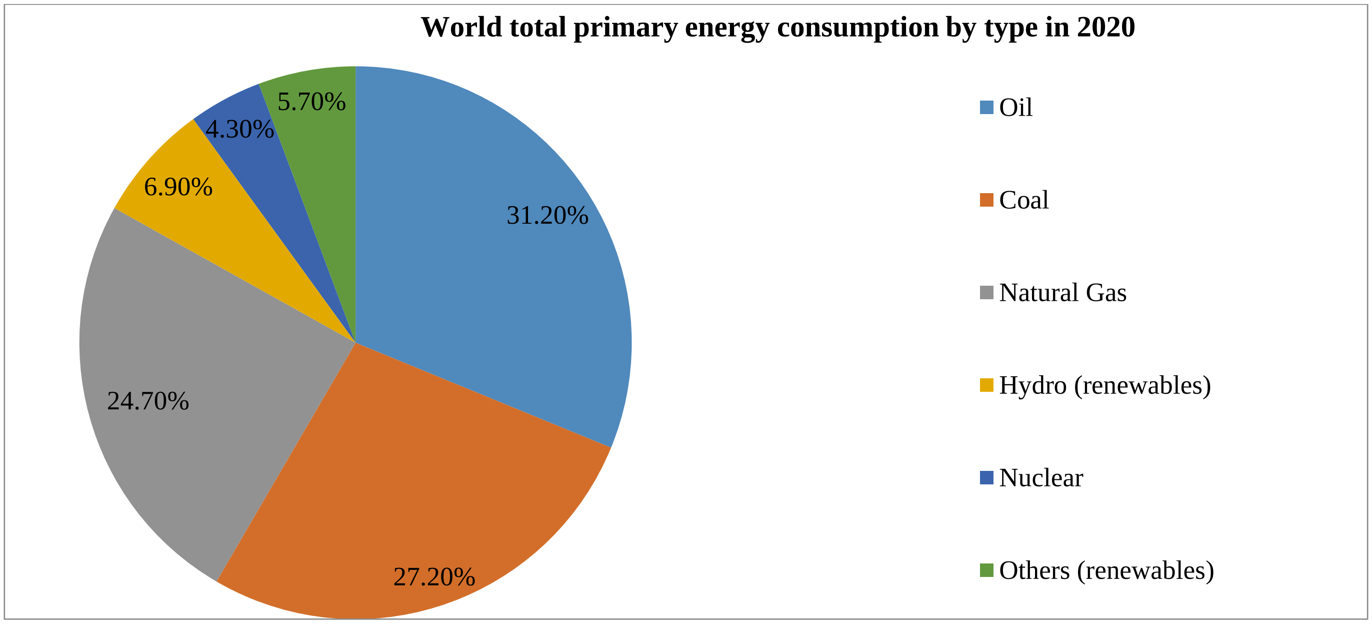


Fig. 1 Total energy consumption by the world in various energy sources [1]

3. Fishery Sector in Oman

The fishery sector is one of the main sectors in Oman that provides job opportunities, and there are more opportunities in this sector to produce young Omani entrepreneurs. Al Kalbaniyeh & Qanat stated that the fishery sector is one of the encouraging sectors that can contribute to developing Oman's economy despite many challenges. He discussed the requirements that the government should provide to expand the fishery sector. He also mentioned in his research paper that the fishery sector may provide 29,000 new job opportunities to the young people of the Sultanate of Oman. The challenges in Oman's fisheries sector are the traditional fishing and storage strategies and the technical gap [2]. There are many challenges in technology implementation in the fishery sector and overcoming weak technical capabilities. Chaudhry et al. [3] discussed the opportunities and challenges in the fishing industry of the Muscat governorate. The authors concluded that the lack of knowledge of Omani fishermen about technologies in fishery science is affecting the opportunities for fishing, marketing the captured fish, storing the fish, and drying the fish to convert fresh fish into dry fish. So, it is clear that the execution of modern technologies in Oman's fishery sector will contribute to sustainable growth and economic development.

The paper's objective is as follows.

- Development of parabolic solar concentrator.
- Development of plate to receive concentrated solar power
- To dry fish to support the fishery sector
- To identify the effective dryness of fishes.

The first key challenge in this project is to design and develop a solar parabolic collector and receiver plate, which will then be set up as a solar dryer. The second key challenge is identifying the quality and dryness of kingfish, which will be used as a sample in this paper.

4. Literature Review

4.1. Review Related to the Solar Dryer for Fishes

Since the application of a solar dryer in this work is at a fishermen's site, the design should be robust and withstand for a more extended period. Also, it requires less skill to operate the system since the fishermen lack the skills to understand the technologies. In their paper, O. Kilanko et al. discussed the Design and Performance Evaluation of a Solar Dryer for agricultural purposes. As per his work, using solar dryers to preserve various crops is an area of growing interest in the agricultural sector [4]. This is useful for smallholder farmers in locations with high solar insolation, like North Central and Northern Nigeria. In this experiment, the author dried the peppers, i.e., with 200g of scotch bonnet peppers, an average of 81.3% w.b. moisture content was removed from the scotch bonnet pepper within three weeks. He identified that the drying chamber temperature was higher than the ambient temperature during most hours of the day. The dryer's efficiency averages 28.4% for galvanized steel solar collectors. Ag Sufiyan bin Abd Hamid et al. 2019 developed a large-scale solar dryer for drying natural fiber in Malaysia [5]. The dryer is designed with many components, such as a solar thermal collector, heat exchanger, and confined polycarbonate chamber. The dryer recorded average solar radiance as 612.84 W/m^2, the ambient temperature 32.42, and the relative humidity 60.01 %. The drying of natural fiber was completed in 3 days, and the weight of the fiber was reduced by 1004.2 kg and 70.7 moisture content on a wet basis. The performance was mentioned as having an evaporative capacity recorded as 68.88 kg/hr. The specific moisture extraction reached around 3.55 kg/kWh, and the specific energy consumption was 0.28 kWh/kg. Pravin M. Gupta et al. have reviewed solar dryers for drying agricultural products. They studied all types of solar dryers but found that indirect solar dryers are more efficient than other dryers and give excellent quality products at a minimum cost[6]. As per the outcome of this paper, the authors claimed that designing the solar dryer for agriculture products is highly efficient at minimum cost. It is helpful for farmers to improve the quality of agricultural products and give them the best price for their products, requiring very little space. It is also used domestically for drying seasoning products. Raghupathy and Balasubramanian studied the solar drying system for fish preservation. As per the study, the solar fish dryer is a multipurpose facility, which is of great importance to the economic growth of coastal fisheries folk.

The authors give the parabolic collector's sunray reflection, shown in Figure 2. Fish drying uses wood or fuels to dry or mechanically place the fish under the open sun. As per the paper, the authors concluded that direct, indirect, and mixed-mode dryers have shown potential in drying agricultural and aquacultural products [7]. So, the solar drying system utilizes solar energy to heat air and dry any food substance, which will be more beneficial in reducing product wastage and help dry and preserve without spoiling the food quality. Abdulrahim Al-Ismaili has written a paper titled "A Review on Solar Drying of Fish" as per AbdulrahimOman, one of the GCC region's larger fish producers.

Due to the high perishable rate of fish products, many preservation techniques were used in Oman, such as smoking, drying, chilling, brining, and freezing [8]. Solar drying is the most popular technique due to its simplicity and low cost compared to other highly suitable techniques for Oman. Shyam S Sablani et al. conducted a solar-based fish drying in Oman. They concluded that "the quality of dried fish was better in the case of solar drying methods due to lower level of contamination from the sand and insects." Also, they have given that the multi-rack drier has a higher efficiency for commercialization due to its large capacity and large surface area per unit of land space. This project shows the positive effect of the solar-based fish drying methodology in the Sultanate of Oman[9].

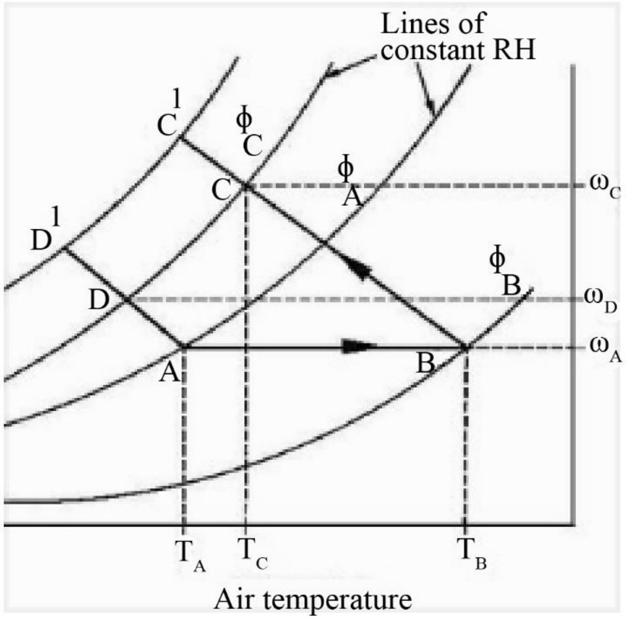


Fig. 2 Solar rays in parabolic collector [7]

Ankurr Nagori et al. published a paper titled "Development of Solar Dryer with Electrical Energy Backup for Hygienic Drying of Fish and Fish Products." This work discusses an efficient design for the solar drying process[10]. Figure 3 shows the design of the solar dryer, which is in a hybrid mode. This dryer will use solar energy during the daytime and electricity at nighttime. The authors have stated that the proposed methodology is economical and the hygiene methodology is more efficient. They have researched and analyzed various parameters such as solar radiation, drying rate, cumulative moisture in fish, etc. However, running a dryer using electricity is more expensive than using a solar dryer.

4.2. Review Related to Dry Fish

Typically, the drying process of the fish is carried out in the open air using sunrays to evaporate moisture content in fish. Moisture content should be reduced below 16% for dry fish to be eatable. Shrinkage and irreversible changes will occur in dried fish. The evaporation rate mainly depends on the environmental conditions during the drying process. Redwan Amin discussed the fish drying process in his article (Shown in Figure 4) and the drying efficiency[11]. Fitri N et al. reviewed dried fish processing and their paper's associated chemical and nutritional changes. The authors concluded that dried fish had higher lipid and protein content than fresh fish [12]. They added that dry fish can be produced using hot air drying, microwave vacuum drying, freeze drying, sun drying, and salt drying. Saragih, A. analyzed the results of using sunlight to dry fish with and without salt. They found differences in the result of drying fish with salt and fish without salt, which vary, such as differences in drying time, fish color, texture, and smell of fish. A salt-based dry fish expiry will be longer compared to non-salt-based dry fish. The texture of salt-based dry fish is less complicated than non-salt-based dry fish [13].

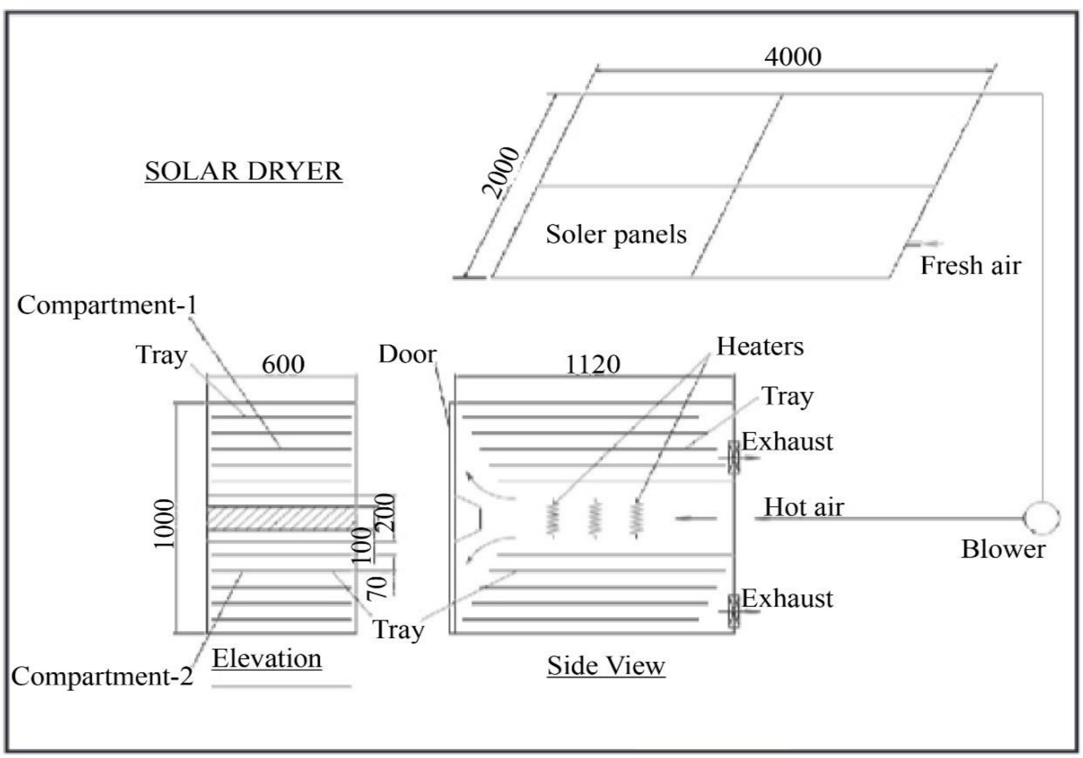


Fig. 3 Solar dryer design [10]

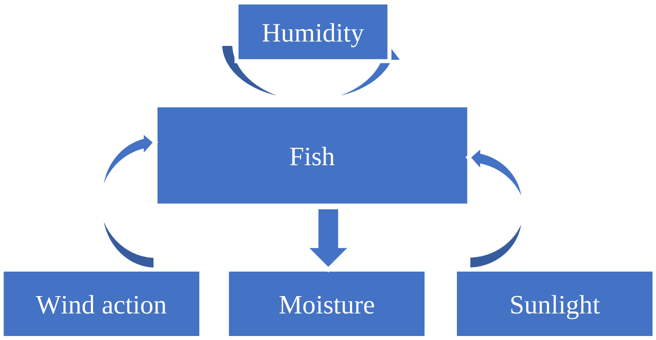


Fig. 4 Fish drying process [11]

Belton, B. has conducted a global survey on dried fish at the intersection of food science, economy, and culture. The authors quote that the dried fish sector employs millions of people, particularly women, who comprise most of the fish-drying workforce in many locations globally. They added that the industry also confronts and creates significant challenges, including food safety concerns and exploitative labor conditions[14]. Aaisha K. Al Saadia has done a microbiological assessment of locally dried fish in Oman. They have taken kingfish samples (locally (in Oman) known as Owal) and analyzed the parameters of Total Fungal Count (TFC), Total Viable Count (TVC), and enumeration of E-Coli, Staphylococcus aureus, and coliforms species in dried kingfish. The authors recommended processing dry fish under more hygienic conditions and using solar driers instead of direct drying on beach sands[15]. Al Subhi K et al. presented a paper in Science Direct titled "An evaluation of Oman's National Fisheries Development Strategy (NFDS) 2013–2020: Wealth or welfare maximization?" From this research, a broader lesson is the importance of balancing the economic benefits of modernization with the social benefits of traditional fishing communities, which mainly focus on the balance many other countries struggle to strike[16].

5. Design and Development of Dryer

This project plans to design a solar-based system to dry fish to help fishermen of the Sultanate of Oman. In Oman, the fishermen face many challenges in selling the fish they are catching from the sea. To improve the economic background of Omani fishermen, new technologies are required in cold storage to preserve the fish. However, when cold storage is unavailable, fishermen prefer a dry fish process to expand their business. In this project, a parabolic-type solar collector will be developed with aluminum plates. After developing the parabolic solar collector, a proper design will be made for a receiver plate to receive the hotness of the parabolic solar collector. On the outside of the collector plate, a cabin will be set up to place the fish that will dry. After finishing the dry project, a system will be developed to check the fish's dryness and identify the drying fish's effectiveness. The design involves the following phases.

- Design and develop solar parabolic collector
- Design of receiver tubes.
- Design of stand for collector and receiver
- Design of box to place Fishes

5.1. Design of Parabolic Collector

The parabolic type collector is a solar thermal energy collector designed to collect the sun's solar radiation over a parabolic surface area, or more generally, "concentrate it" onto a small focal point area to increase the solar energy concentration, which is received by more than a factor of two which means more overall heat per square meter of the trough.

The shape of concentrating solar collectors must be specifically designed so that all the inward sunlight reflects off the surface of the collector and arrives at the same focal point no matter what part of the collector the sunlight hits first. The concept of a parabolic-type concentrator is given in Figure 5. The following are the advantages of using a parabolic collector.

- Inexpensive
- Create high temperature on concentrating place
- Cheap reflector and more span area
- Maximize harvesting solar energy
- High conversion ability from solar to thermal

Concentrating more on the design of solar collectors is required. If there is a design fault, the concentration of solar energy will be limited, and efficiency will decrease. So, to maximize efficiency, a meticulous design of solar collectors is needed.

The graphical abstract given by the authors Evangelos Bellos and Christos Tzivanidis with parabolic and a heat exchanger is presented in Figure 6. This system uses an evacuated tube as a receiver to collect the thermal energy [17]. The nomenclature for the design is shown in the table 1.

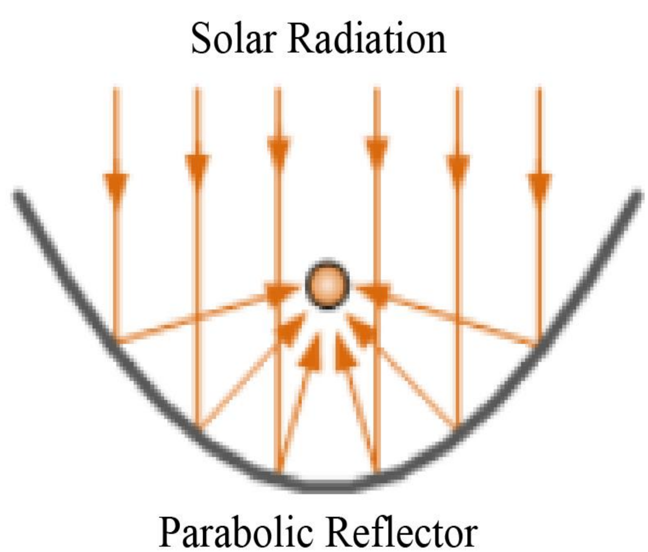


Fig. 5 Concept of Parabolic type concentrator [18]

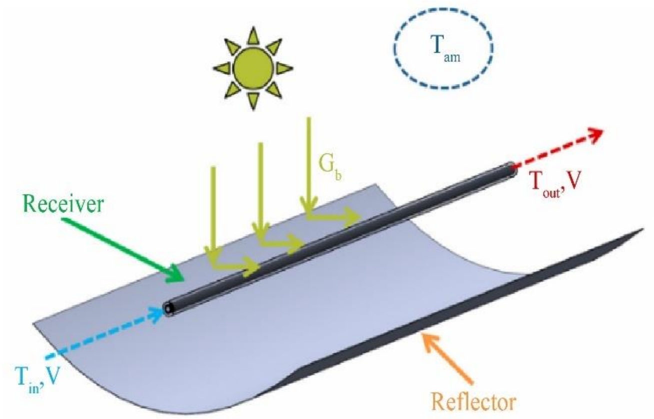


Fig. 6 Design abstract for parabolic trough collector [17]

Table 1. Nomenclature for the design of parabolic solar collector

A	Area, m2	K1	Coefficient of Equation (4), W/K
C	Concentration ratio	K2	Coefficient of Equation (11), W/K4
cp	Specific heat capacity under constant pressure, J/kg K	K3	Coefficient of Equation (17), W/K
D	Diameter, m	K4	Coefficient of Equation (25)
f	Collector focal distance, m	K5	Coefficient of Equation (25), W/K4
Gb	Solar direct beam radiation, W/m2	L	Collector length, m
h	Heat transfer coefficient between fluid and absorber, W/m2 K	m	Mass flow rate, kg/s
hout	Heat transfer coefficient between cover and ambient, W/m2 K	Nu	Nusselt number
k	Thermal conductivity, W/mK	Pr	Prandtl number
K	Incident angle modifier	Q	Heat flux, W
Re	Reynolds number	V	Volumetric flow rate, m3/s
T	Temperature, K	W	Collector width, m

The design steps involved in parabolic trough collector are as follows.

STEP 1

The thermal losses from the cover to the ambient (radiation and convection losses) can be written as below (contact thermal losses are neglected)

$$Q_{\text{loss}} = A_{co} \times \hat{\imath}_c \times \sigma \times (T_c^4 - T_{am}^4) + A_{co} \times h_{out} \times (T_c - T_{am}) \quad (1)$$

The cover temperature is assumed to be close to the ambient temperature because of the existence of an evacuated tube collector. It can be written as follows.

$$T_c^4 = T_{am}^4 \approx 4 \times T_{am}^3 \times (T_c = T_{ami}) \quad (2)$$

Equation (2) validity is tested by comparing this model with other models.

Using Equations (1) and (2), it can be written:

$$Q_{\text{loss}} = [A_{\omega 0} \times \varepsilon_c \times \mathbb{F} \times 4 \times T_{am}^3 + A_{\omega 0} \times h_{\text{out}}] \times (T_c - T_{amm}) \quad (3)$$

$$\text{of } Q_{\text{loss}} = K_1 \times (T_c - T_{\text{arift}}) \quad (4)$$

with

$$K_1 = A_{\omega j} \times \varepsilon_c \times \sigma \times 4 \times T_{am}^3 + A_{c0} \times h_{\text{out}} \quad (5)$$

STEP 2

The thermal losses of the absorber to the cover are only radiation losses because of the vacuum between the absorber and the cover (there are no convection thermal losses):

$$Q_{loss} = A_{ro} \times \varepsilon_r^* \times \sigma \times (T_r^4 - T_c^4) \quad (6)$$

with

$$\varepsilon_r^* = \left[\frac{1}{\varepsilon_r} + \frac{1-\varepsilon_c}{\varepsilon_c} \times \frac{A_{ro}}{A_{ci}}\right]^{-1} \quad (7)$$

Equation (6) can be written as follows. It is essential to state that the cover has been assumed to radiate to the ambient conditions.

$$Q_{loss} = A_{ro} \times \varepsilon_r^* \times \sigma \times (T_r^4 - T_{aNH}^4) - A_{ro} \times \varepsilon_r^* \times \sigma \times (T_c^4 - T_{aNN}^4) \quad (8)$$

Using Equations (2) and (4), it can be written:

$$T_c^4 - T_{am}^4 = \frac{4 \times T_{am}^3}{K_1} \times Q_{loss} \quad (9)$$

Using Equations (8) and (9), it can be said:

$$Q_{loss} = A_{ro} \times \varepsilon_r^* \times \sigma \times (T_r^4 - T_{am}^4) \times \left[1 + \frac{4 \times T_{am}^3 \times A_{ro} \times \varepsilon_r^* \times \sigma}{K_1}\right]^{-1} \quad (10)$$

or

$$Q_{\text{loss}} = K_2 \times (T_r^4 - T_{am}^4) \quad (11)$$

with

$$K_2 = A_{r0} \times \varepsilon_r^* \times \sigma \times \left[1 + \frac{4 \times T_{a+H}^3 \times A_{r0} \times \varepsilon_r^* \times \sigma}{K_1}\right]^{-1} \quad (12)$$

STEP 3

The useful heat can be calculated using the energy balance in the fluid volume:

$$Q_u = m \times c_p \times (T_{\text{out}} - T_{\text{in}}) \quad (13)$$

Furthermore, it can be calculated using the heat transfer from the receiver to the fluid:

$$Q_u = A_{ri} \times h \times (T_r - T_{fm}) \quad (14)$$

The mean fluid temperature can be estimated as:

$$T_{fm} = \frac{T_{\text{in}} + T_{\text{out}}}{2} \quad (15)$$

Using the Equations (13)-(15), it can be written:

$$Q_u = \left[\frac{1}{A_{ri} \times h} + \frac{1}{2 \times m \times c_p}\right]^{-1} \times (T_r - T_{in}) \quad (16)$$

Or it can be written as

$$Q_u = K_3 \times (T_r - T_{in}) \quad (17)$$

with

$$K_3 = \left[\frac{1}{A_{ri} \times h} + \frac{1}{2 \times m \times c_p}\right]^{-1} \quad (18)$$

STEP 4

The Equation (11) can be transferred as

$$Q_{\text{loss}} = K_2 \times (T_r^4 - T_{in}^4) + K_2 \times (T_{in}^4 - T_{am}^4) \quad (19)$$

The temperature difference between the receiver and fluid can be written using Taylor series

$$T_r^4 - T_{in}^4 \approx 4 \times T_{in}^3 \times (T_r - T_{in}) \quad (20)$$

Using Equations (17) and (20), it can be written:

$$T_r^4 - T_{in}^4 \approx \frac{4 \times T_{in}^3}{K_3} \times Q_u \quad (21)$$

Using Equations (19) and (21), Q_{loss} can be written as

$$Q_{loss} = \frac{4 \times T_{in}^3 \times K_2}{K_3} \times Q_u + K_2 \times (T_{in}^4 - T_{am}^4) \quad (22)$$

STEP 5

The energy balance in the absorber indicates that the absorbed energy is converted into proper heat and thermal losses. The absorbed energy equals the optical efficiency multiplied by the direct beam solar irradiation. Thus, it can be written:

$$\eta_{\text{opt}} \times Q_s = Q_u + Q_{\text{loss}} \quad (23)$$

Using Equations (22) and (23), it can be written:

$$Q_u = \left[\eta_{opt} \times Q_s - K_2 \times (T_{in}^4 - T_{am}^4)\right] \times \left[1 + \frac{4 \times T_{in}^3 \times K_2}{K_3}\right]^{-1} \quad (24)$$

or

$$Q_u = K_4 \times Q_s - K_5 \times (T_{in}^4 - T_{am}^4) \quad (25)$$

with

$$K_4 = \eta_{\text{opt}} \times \left[1 + \frac{4 \times T_{\text{in}}^3 \times K_2}{K_3}\right]^{-1} \quad (26)$$

and

$$K_5 = K_2 \times \left[1 + \frac{4 \times T_{in}^3 \times K_2}{K_3}\right]^{-1} \quad (27)$$

The other relevant parameter calculations are as follows:

The thermal efficiency of the solar collector (η_{th}) can be calculated as:

$$\eta_{th} = K_4 - K_5 \times \frac{(T_{in}^4 - T_{am}^4)}{A_a \times G_b} \quad (28)$$

Using Equations (23) and (25), the thermal losses (Q_{loss}) can be calculated as:

$$Q_{\text{loss}} = (\eta_{\text{opt}} - K_4) \times Q_s + K_5 \times (T_{\text{in}}^4 - T_{\text{am}}^4) \quad (29)$$

Using Equations (17) and (25), the receiver temperature (T_r) can be calculated as:

$$T_r = T_{in} + \frac{K_4}{K_3} \times Q_s - \frac{K_5}{K_3} \times (T_{in}^4 - T_{am}^4) \quad (30)$$

Using Equations (4) and (25), the cover temperature (T_c) can be calculated as:

$$T_c = T_{am} + \frac{\eta_{\text{opt}} - K_4}{K_1} \times Q_s + \frac{K_5}{K_1} \times (T_{\text{in}}^4 - T_{\text{am}}^4) \quad (31)$$

Using Equations (13) and (25), the fluid outlet temperature (T_{out}) can be calculated as:

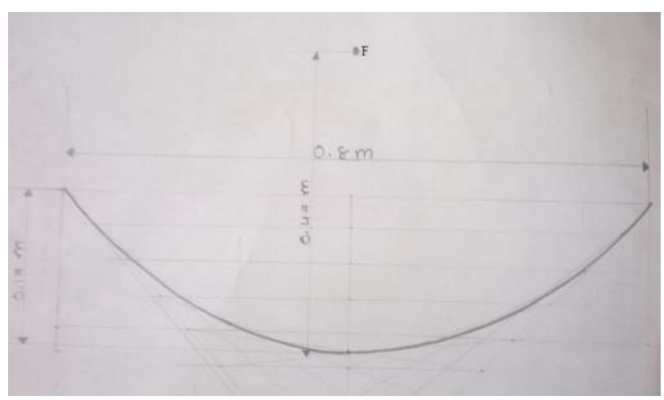
$$T_{\text{out}} = T_{\text{in}} + \frac{K_4}{m \times c_p} \times Q_s - \frac{K_5}{m \times c_p} \times (T_{\text{in}}^4 - T_{\text{am}}^4) \quad (32)$$

Using Equations (15) and (32), the mean fluid temperature (T_{fm}) can be calculated as:

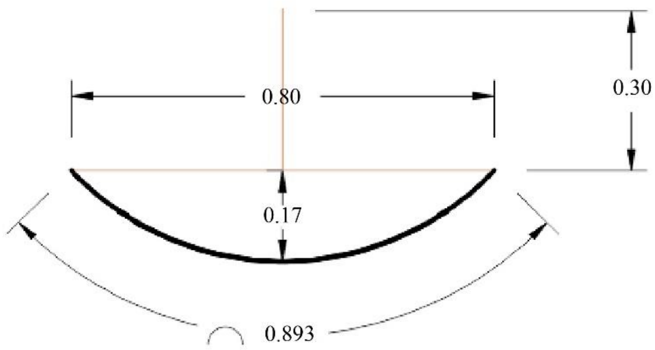
$$T_{fm} = T_{in} + \frac{K_4}{2 \times m \times c_p} \times Q_s - \frac{K_5}{2 \times m \times c_p} \times (T_{in}^4 - T_{am}^4) \quad (33)$$

5.2. Design of Solar Collector

Solar thermal collector traps the sunlight or absorbs solar radiation to generate solar energy for different applications. Solar collectors absorb/concentrate solar from sun radiation. This device primarily absorbs heat and transfers heat to water or heat transfer fluid. The design has been fabricated using CAD model software based on the pencil sketch**.** The CAD model in Figure 7 (a,b,c) shows a parabolic collector with two legs. There is a support system in which the parabolic concentrator can be easily titled according to the sun's direction. Table 2 shows the dimensions of the proposed parabolic collector.



(a)



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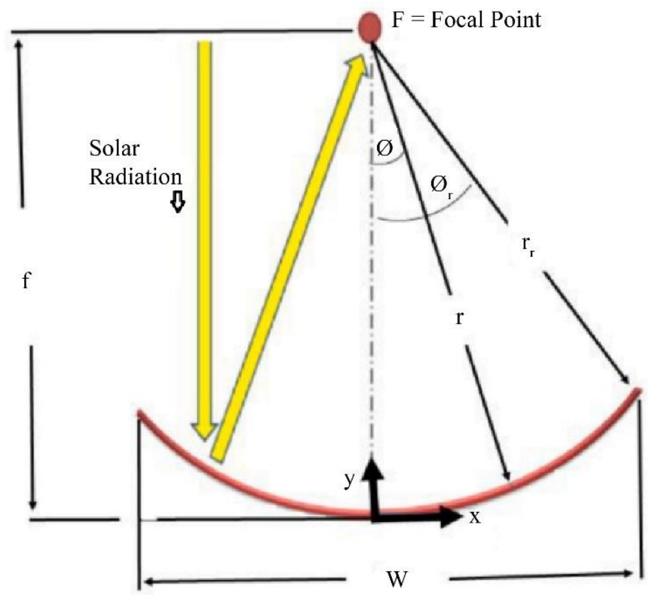


(c)

Fig. 7 Parabolic collector design (a) Pencil drawing (b) Auto CAD drawing (c) Geometry of concentrator [19]

Table 2. Parabolic collector dimensions

Description	Dimensions
Width of the aperture of the Parabolic collector	0.8 m
Parabola focal distance	0.893 m
The radius of the parabola	0.47m
Parabolic collector length	1.5m
Parabolic collector width	0.8m
Arc radius	0.17m
Materials	Al plates, GI Pipes, MS Sheets, and wood

Fabrication is essential to every project because it provides a clear idea of the work being executed in real-time. However, this has to be followed to achieve the analysis and implementation with the best result. It is so, considering that decent and correct attention has been paid to fabrication work. The beginning of the stage is used to select the materials, and the next step is the fabrication phase. We have to ensure the design is perfect before selecting materials and the machining process. The CAD model for parabolic design is given in Figure 8. If there are any limitations, we need to choose the best methods to do the fabrication. The next step is determining the requirements of the project and the need to execute it accordingly.

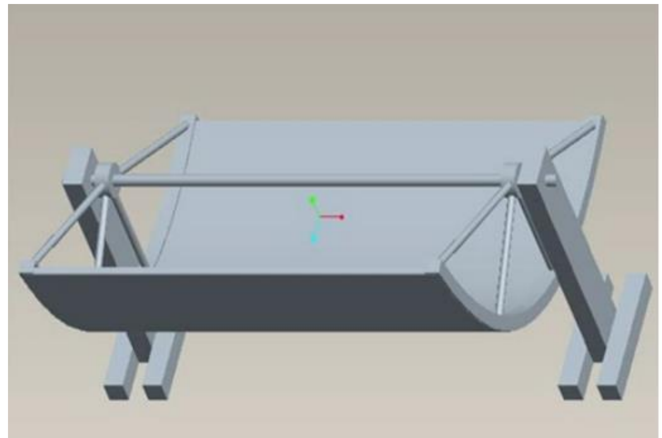


Fig. 8 CAD model for parabolic design

Fig. 9 Side and Top view of fabricated solar dryer

The final step is testing and analyzing the results to ensure the project has been completed and implemented per the requirements. The aluminum sheet is bent according to the design and the angle suggested in the initial fabrication work. A die made the trough perfectly smooth, and then the Al sheet was bent. The support angles were provided after the bend. A square support is offered to keep the Al sheet without any movement. The legs are carefully designed to withstand the weight of the parabolic setup. Figure 9 shows the various views of the setup.

5.3. Solar Receiver

A receiver for use with parabolic solar concentrators consists of a heat-conductive tube helically coiled into a hollow cone shape. Heat-conductive fluid is pumped into an entry point in the tube and exits at an exit point from the tube. A casing is provided to cover the cone. An insulator between the cone and casing prevents heat from escaping from the coil. Solar stands and fish stands were also designed for the experiment. A single copper tube with an inner diameter of 40 mm and an outer diameter of 42 mm has been designed and developed. The tube length has taken slightly longer than the length of the parabolic concentrator. The size of the tube is designed to be 1.57 m. The copper tube was painted black to improve absorptivity.

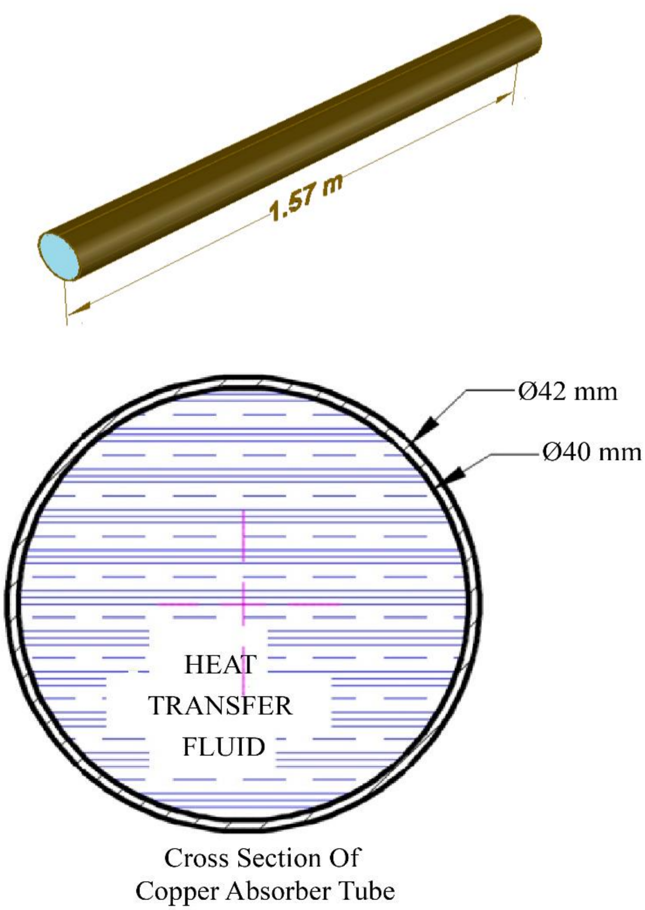


Fig. 10 Design of single evacuated copper tube absorber

Table 3. Solar absorber dimensions

Description	Dimensions
Length	1.57 m
Outer Diameter	42 mm
Inner diameter	40 mm
Thickness of wall	2 mm
Material	copper
Type	Single tube absorber

The ends of the copper tube were sealed at both ends by thermal silicone material. A vacuum pump was used to remove the airlock inside the tube. Using copper tubes has the advantages of copper high mechanical strength, low weight, ease of fabricating, improved absorptivity, and corrosion-resistant properties. The copper tube used for the experiment is shown in Figure 10, and the dimensions are given in Table 3. After finishing the fabrication, the mounting structure for the fish has been fabricated. The mounting structure should be placed as needed to focus all the collected energy on the fish that will dry. Aluminum trays can be painted black to increase their absorptivity. Generally, aluminum has good thermal conductivity so these trays can heat quickly. The fish have been put in the heating tray to absorb the heat fully.

5.4. Design of Tracking Mechanism

The tracking mechanism is interdisciplinary work. It is a combination of electronic and mechanical design that tracks the sun. The tracking system used a simple voltage balance, where the output of two small PV panels worked against each other. Figure 11 shows the basic principle of the tracking mechanism. In this, a photo sensor is placed to detect the sun. The information is fed into an electronic board. The electronic board is energized with a battery, which is recharged by PV panels. There is a charge controller to control the voltage coming from PV panels. The east-west rotation will be based on sun tracking using a photo sensor. Once sunset comes, there is a limit switch in the stand which will trigger a relay so that the DC motor will rotate the parabolic trough to the home position (morning position)

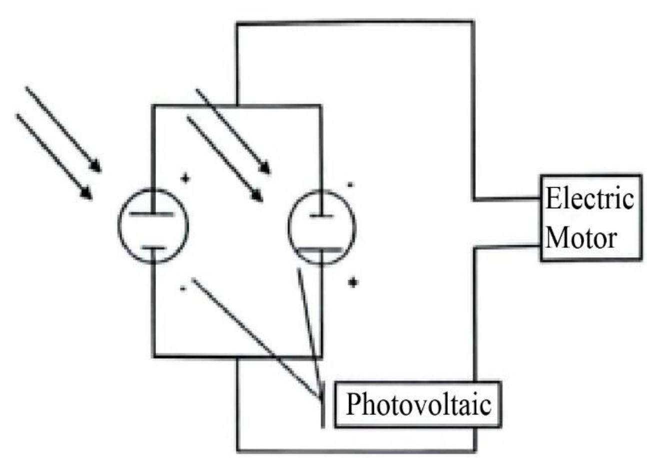


Fig. 11 Automatic sun tracking system

The methodology of experimental steps is as follows.

- Design of parabolic collector
- Design of absorber
- Design of automatic tracker
- Design of Stand
- Fabrication of Collector, receiver, and stand
- Development of Solar tracker using sensor
- Fabrication of tray to dry fishes
- Assembly of the components

After the development of the Solar dryer, the following is the description of the drying process. Initially, the king is kept at the tray where heat will be focused. The parabolic trough will collect sunrays and concentrate on the focal line. On the focal line, a single evacuated copper tube is placed. So, an evacuated copper tube absorbs solar radiation and converts it into heat. The heat generated in the tube will be transferred to the chamber/tray where the fish are placed. The vacuum in the tube minimizes heat loss to improve thermal efficiency.

6. Discussion and Analysis of the Solar Dryer

The efficiency of the parabolic solar collector is calculated and graphically represented to compare different sun radiation, heat production, and moisture content in the fish at various times. Solar performance will vary from time to time because of environmental variation. So, solar collectors collect sunlight's heat according to the climatic conditions. The summer climate is different from the winter climate, and sunny days are also different from winter days. According to the test conducted in the solar collector, many parameters, such as temperature, humidity, and solar radiation, have been calculated. These parameters were tested at the beginning of the hot summer in Oman and in the morning and evening. Kingfish (Locally known as Owal) is a medium-sized sample weighing 5 kg. Four fish were taken in the tray for a total weight of 20 kg. The same kind of samples were taken for three trials, and the statistics were taken for all days but tabulated only for three days for one best trial. All trials were taken in April of Oman; three days were taken to dry the fish by trailing to remove 85 to 90% of the moisture content from fresh fish. In the fourth trial, big-size fish were taken and found more days to dry. In Oman condition, in our solar dryer model, for kingfish drying, it took six days for big-size fish and three days for medium-sized fish during the April period. Tables 4, 5, and 6 show the various parameters during the drying process of the fish. The fish wholly dried and gave three days 1/3 weight loss in overall kg. So,14kg was reduced from 20 kg of fish, which means 6kg of dry fish was collected from the solar dryer. The temperature, change of radiation, and relative humidity do not change much during the three days of the testing period in 2024. The time vs. other parameters has been analyzed using a line chart and bar chart in the Excel sheet and recorded in Figures 12,13, and 14.

Table 4. Time vs various parameters (Day 1)

Time	Temperature In Celsius	Change of Solar radiation (w/m2)	Relative humidity	Weight loss In kg (From 20kg)
7.15	28.3	600.8	55.2	0
8.15	29.1	700.3	58.4	0.5
9.15	30.4	750.4	60.5	1
10.15	34.5	800.5	62.5	1.4
11.15	34.2	820.6	64.3	2.1
12.15	35.6	900.7	65.5	2.6
13.15	35.5	880.4	62.5	2.8
14.15	34.6	800.6	60.6	3.0
15.15	32.2	700.6	58.6	3.5
16.15	31.5	560.3	55.5	4.0
17.15	30.8	400.4	54.4	4.5

Table 5. Time vs various parameters (Day 2)

Time	Temperature	Change of Solar radiation (w/m2)	Relative humidity	Weight loss In kg (from 20kg)
7.15	28.2	650.2	56.5	4.5
8.15	29.3	700.8	59.4	5.0
9.15	30.3	750.6	61.5	5.2
10.15	34.1	820.3	64.5	5.4
11.15	34.2	820.5	66.4	6.0
12.15	35	900.4	66.4	7.0
13.15	35.1	870.5	61.5	7.5
14.15	34.3	820.6	60.2	8.0
15.15	32.3	710.2	59.3	8.4
16.15	31.2	570.1	53.1	8.6
17.15	30.8	450.8	52.5	8.8

Table 6. Time vs various parameters (Day 3)

Time	Temperature	Change of Solar radiation (w/m2)	Relative humidity	Weight loss In kg (From 20 Kg)
7.15	29.2	660.4	56.6	8.8
8.15	29.3	720.5	59.4	9.0
9.15	30.5	750.6	61.2	9.2
10.15	32.1	810.3	64.5	9.8
11.15	34.2	830.5	66.6	10.6
12.15	35.6	920.6	66.6	11.0
13.15	35.8	860.6	61.7	11.8
14.15	34.2	830.3	60.2	12.5
15.15	32.3	720.2	59.7	13.0
16.15	31.3	580.4	53.5	13.5
17.15	30.9	460.8	52.2	14.0

To analyze the solar dryer's performance, the parameters of heat transfer, solar irradiation, thermal efficiency, fish drying efficiency, etc., must be calculated. The following formulas will help calculate these parameters.

The relevant other parameters calculations are as follows:

$$Qu = mf \times cp\ (Tout - Tin) \quad \ldots..\ (34)$$

Where, mf = Mass flow rate(0.008055 kg/sec) Cp = Specific heat capacity in Kj/kg k = 4.2 KJ/ kg k

Mass flow rate = Density of fluid x Velocity of fluid x Area of the tube ….(35)

Moreover, the solar irradiation (Qs) can be calculated from the equation

$$:QS = Aa \times Gb \quad \ldots.(36)$$

Where Aa is the aperture of the collector, which can be calculated as Aa = W × L W= width and L= Length

Gb = Direct beam radiation in W/m2

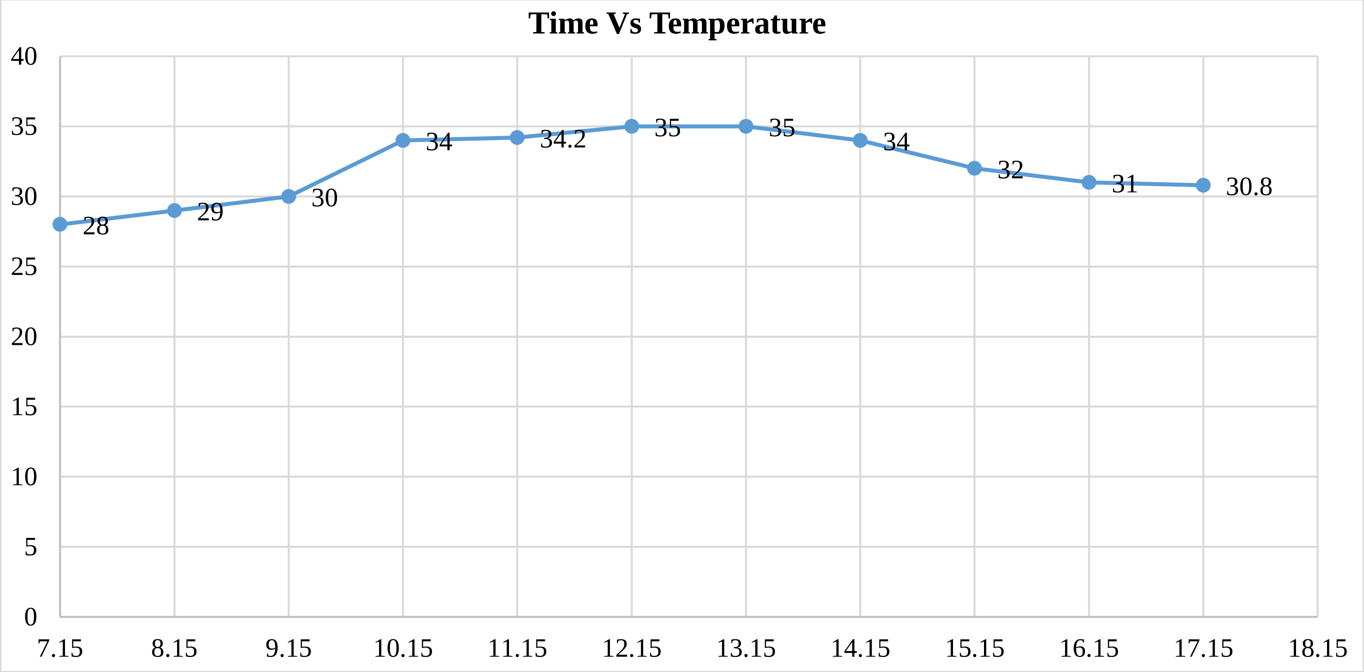
that is used to calculate thermal efficiency is as follows

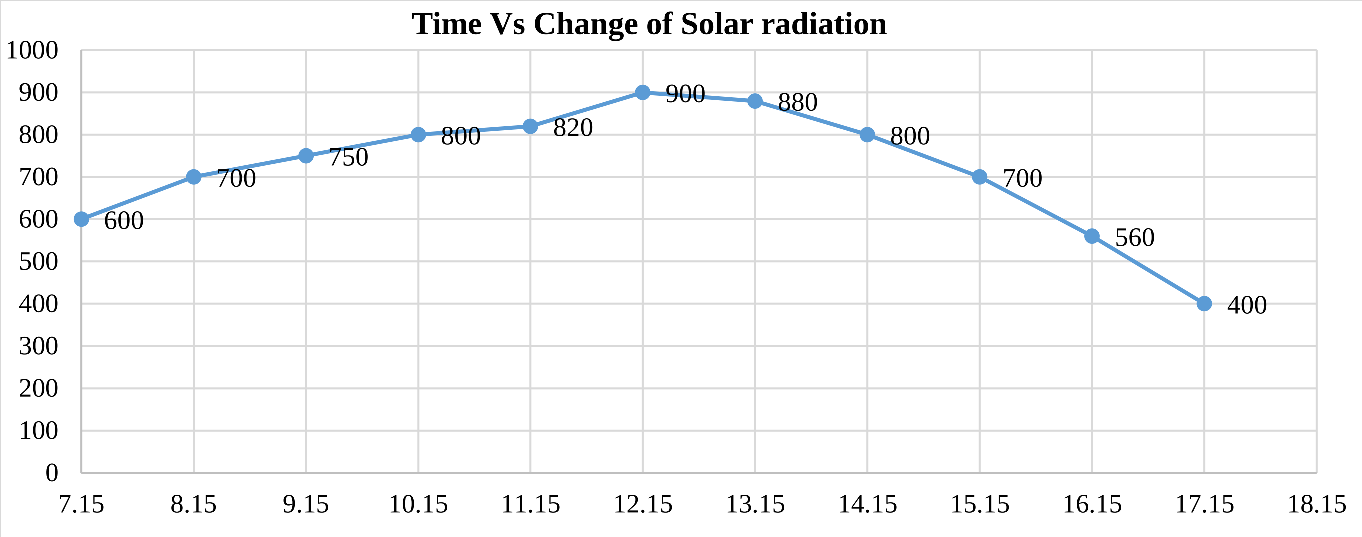
$$\eta th = Qu / Qs \quad \ldots.(37)$$

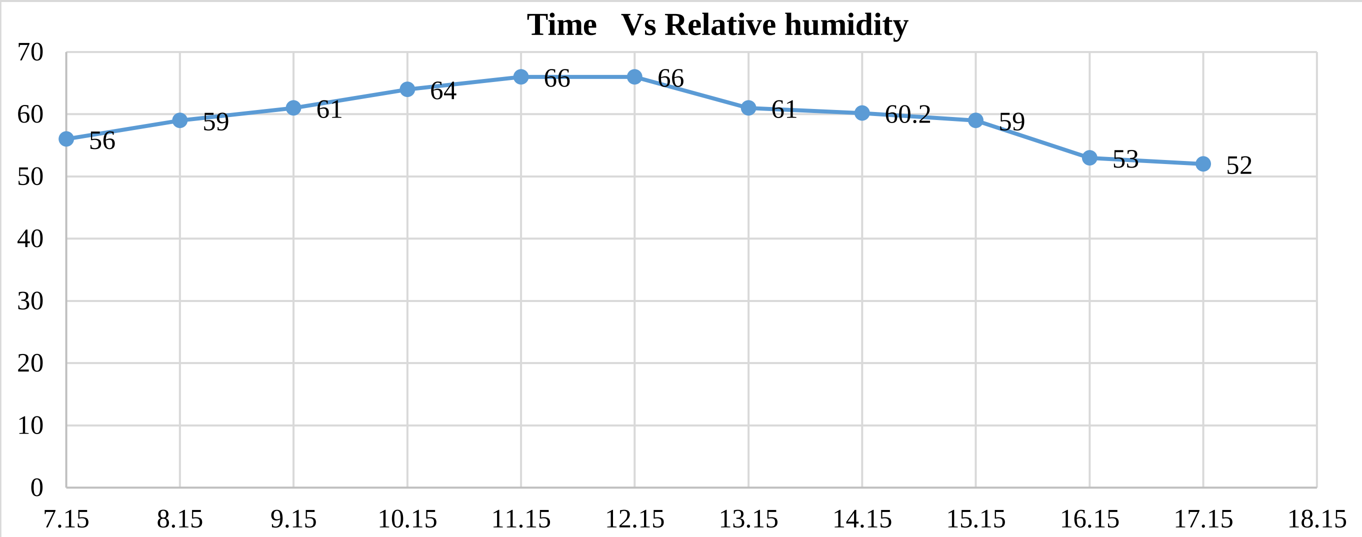
(Mass flow rate = 29 kg/hr = 0.008055 kg/sec;Cp = 4200 J kg-1 k-1)

Figures 12, 13, and 14 show the various parameters concerning the time variation during the testing period. The copper receiver tube will carry heat transfer fluid to dry the fish. Different parameters related to receiver fluid flow and drying efficiency have been calculated.

The temperature of the liquid in and out has been measured and tabulated. After finding the temperature, the drying efficiency of the fish was calculated by finding moisture removal from the fish.







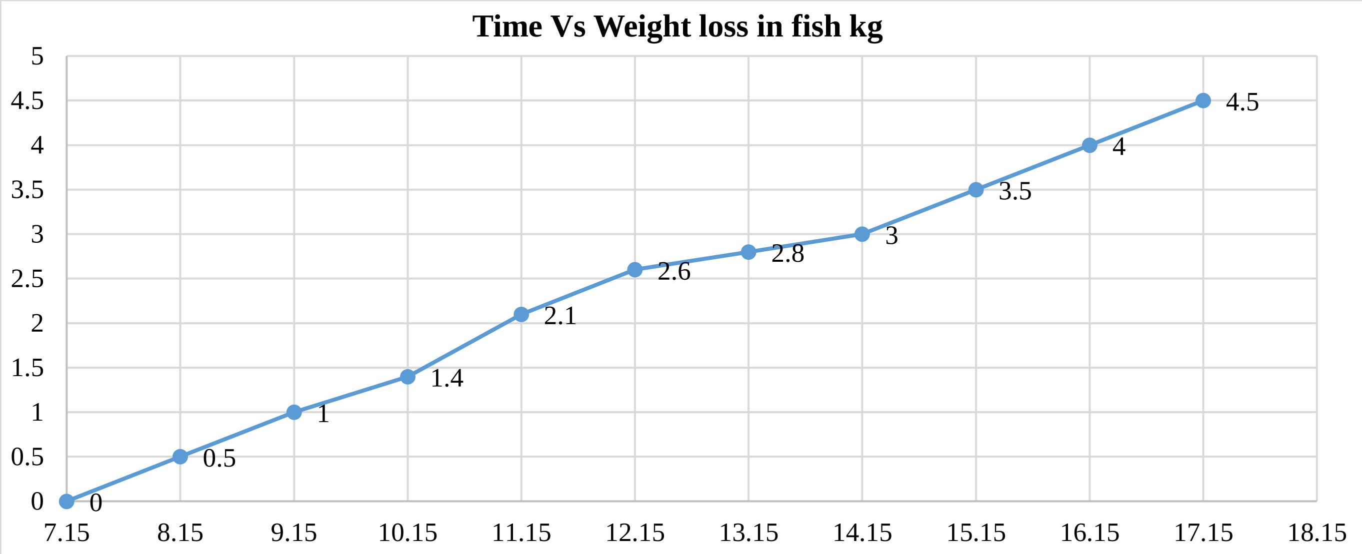
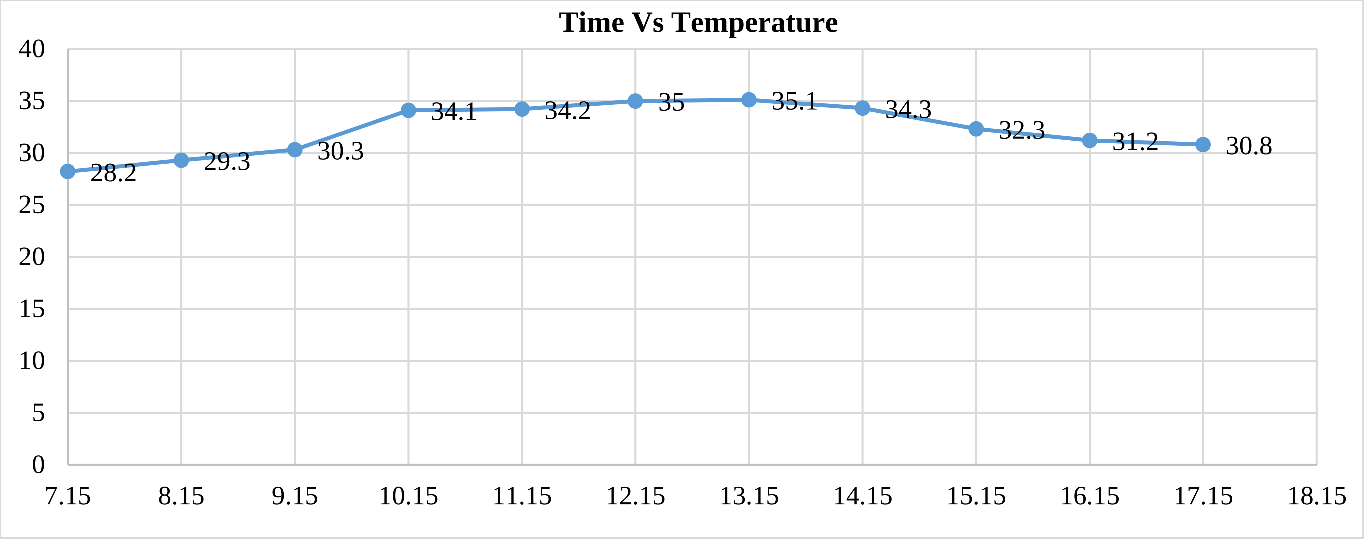


Fig. 12 Parameter Analysis (Day 1 Statistics)


Time Vs Temperature
40
35
30
25
20
15
10
5
0
28.2
29.3
30.3
34.1
34.2
35
35.1
34.3
32.3
31.2
30.8
7.15
8.15
9.15
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11.15
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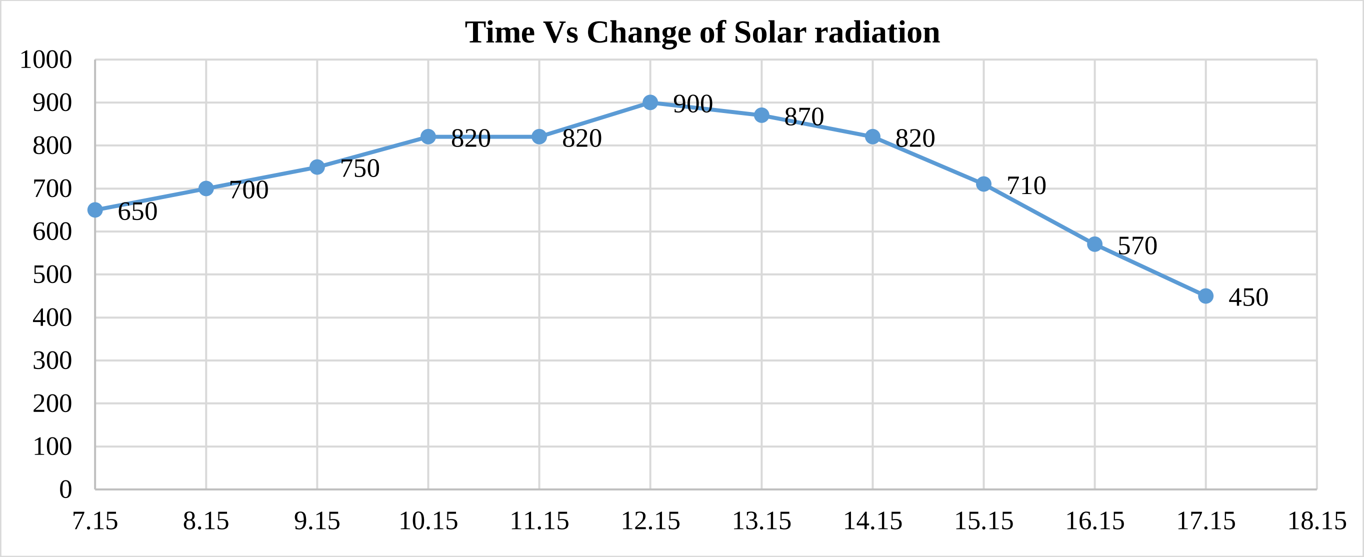
13.15
14.15
15.15
16.15
17.15
18.15


Time Vs Change of Solar radiation
1000
900
800
700
600
500
400
300
200
100
0
650
700
750
820
820
900
870
820
710
570
450
7.15
8.15
9.15
10.15
11.15
12.15
13.15
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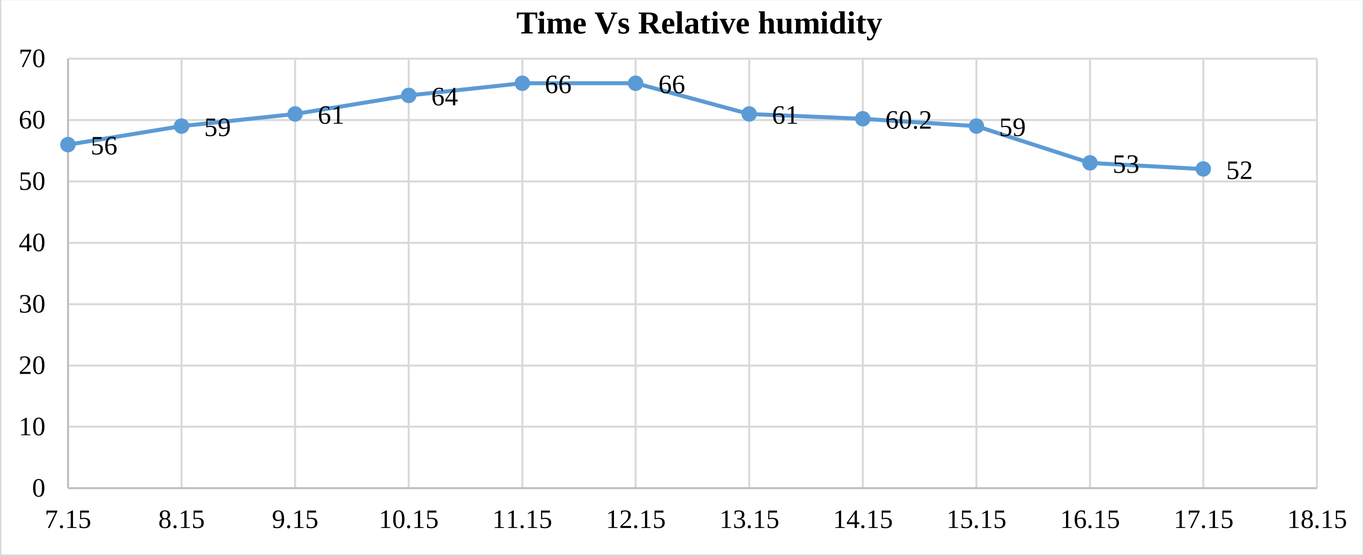
15.15
16.15
17.15
18.15


Time Vs Relative humidity
70
60
50
40
30
20
10
0
56
59
61
64
66
66
61
60.2
59
53
52
7.15
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16.15
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18.15

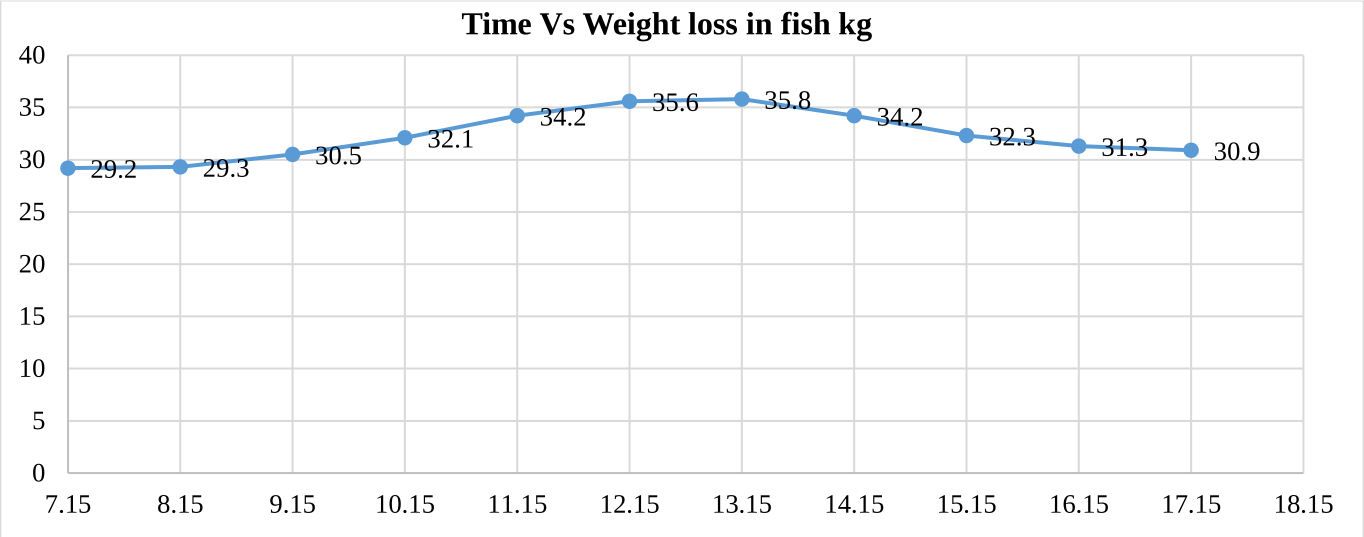
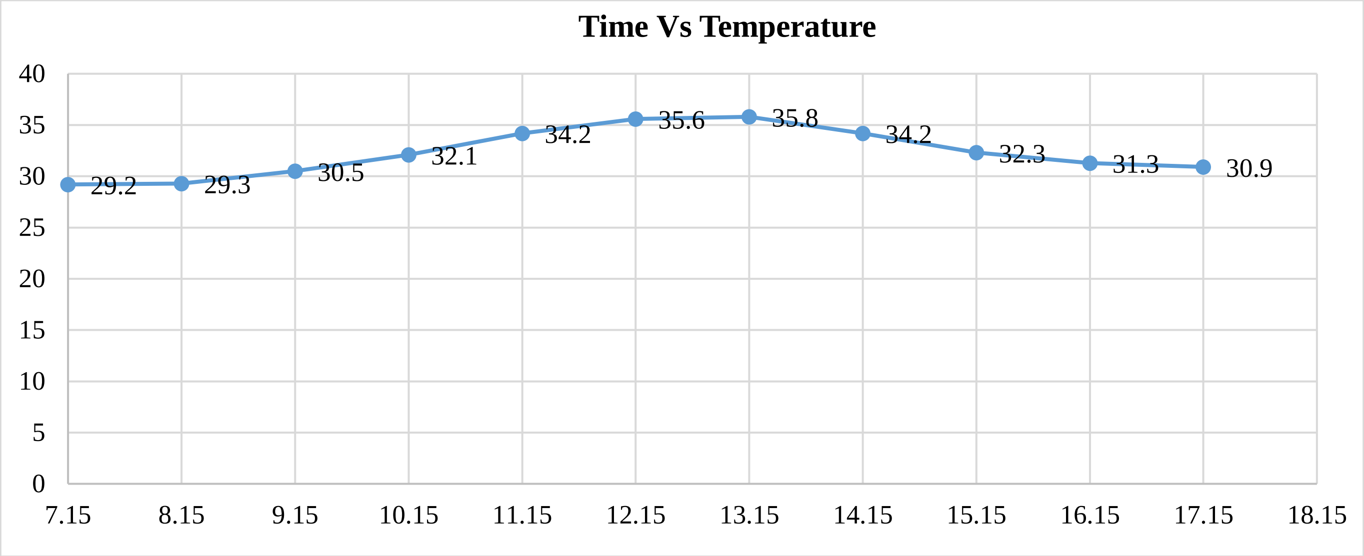
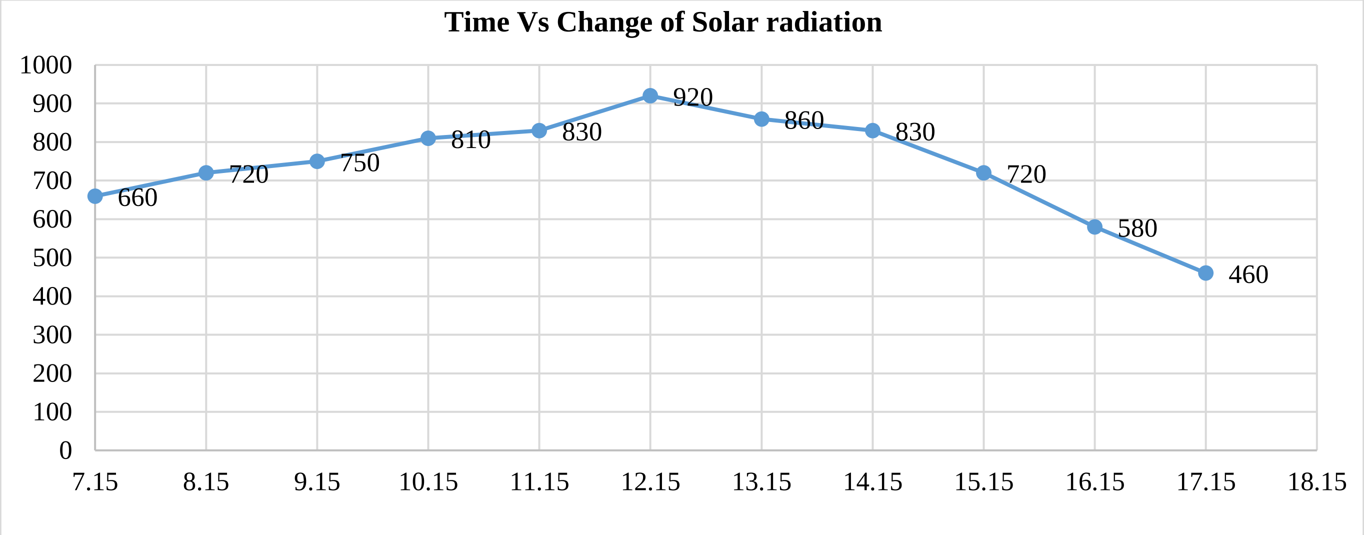
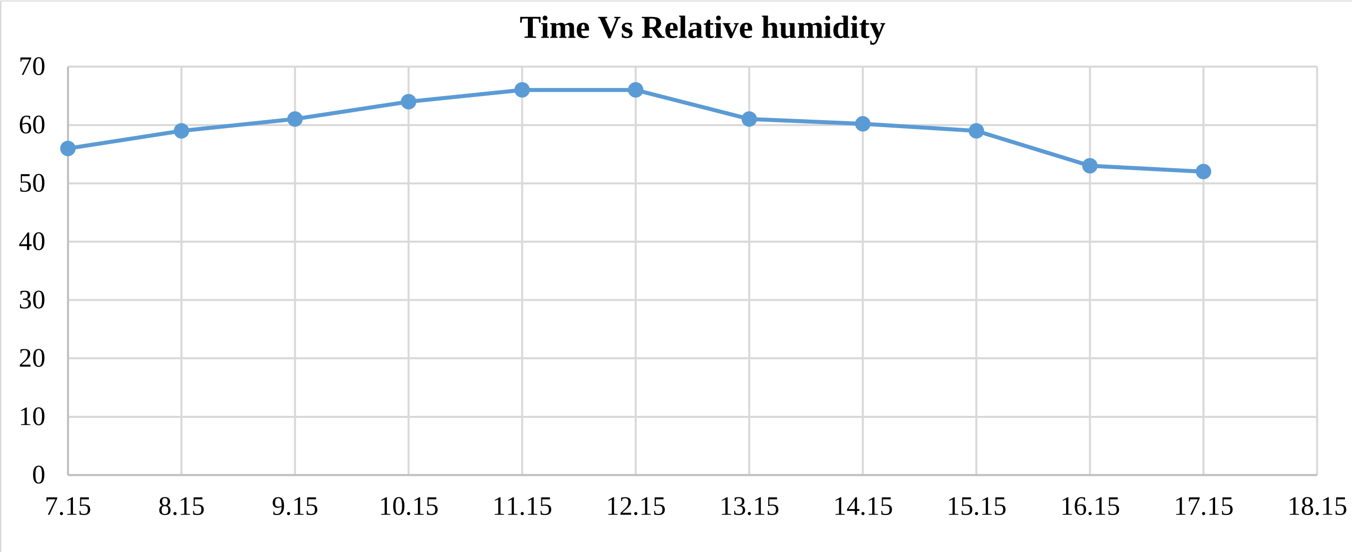


Fig. 13 Parameter analysis (Day 2 statistics)







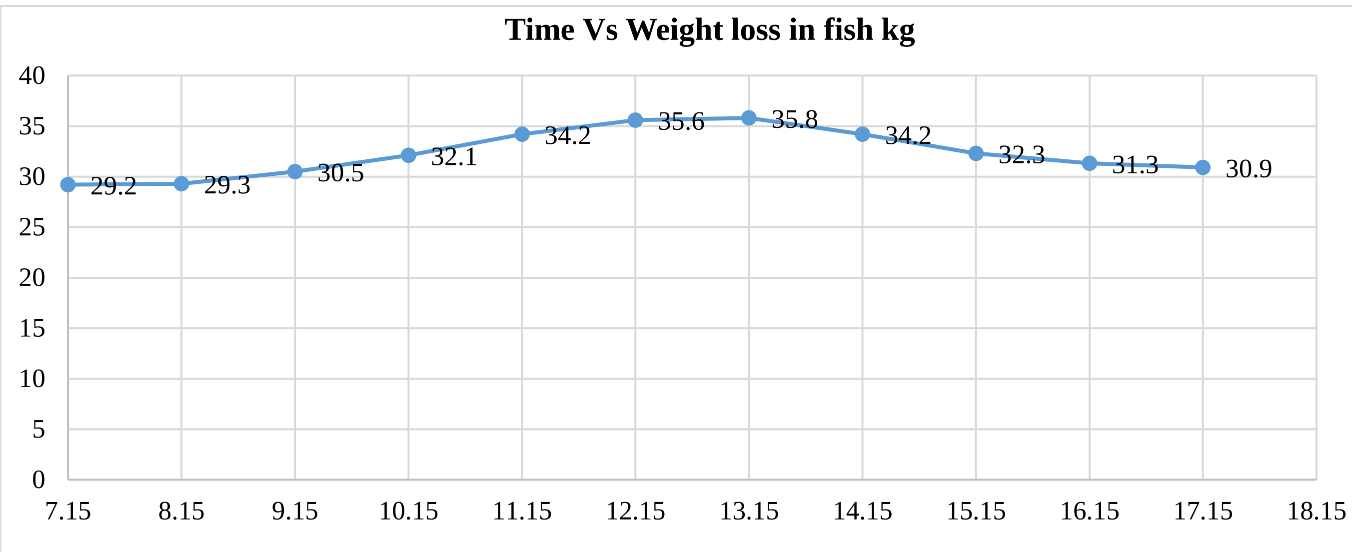


Fig. 14 Parameter analysis (Day 3 statistics)

Tables 7, 8, and 9 show the drying efficiency, and Figure 15 shows the efficiency variation due to variation of radiation from the sun. The recorded temperature is shown in Figure 16. The average efficiency of solar collectors for day 1, day 2, and day three has been recorded as 78.2%,72.9%, and 75.9%.

Overall solar collector efficiency for fish drying has been calculated as follows

= (78.2+75.9+79.7)/3
= 77.9%

Table 7. Various temperatures and the efficiency of solar collector (Day 1)

	Time	G_b in W/m^2	T_{am} In C	T_{in} in C	T_{out} in C	Drying Efficiency	% Drying Efficiency %η
	7.15	600.8	28.3	32.2	36.5	0.771123	77.1
	8.15	700.3	29.1	32.8	37.6	0.738486	73.8
	9.15	750.4	30.4	33.7	39	0.760971	76.0
	10.15	800.5	34.5	34.3	40.2	0.794101	79.4
	11.15	820.6	34.2	37.5	43.8	0.827169	82.7
	12.15	900.7	35.6	40.1	46.4	0.753608	75.3
Day 1	13.15	880.4	35.5	39.0	45.4	0.783222	78.3
	14.15	800.6	34.6	38.5	44.5	0.80746	80.7

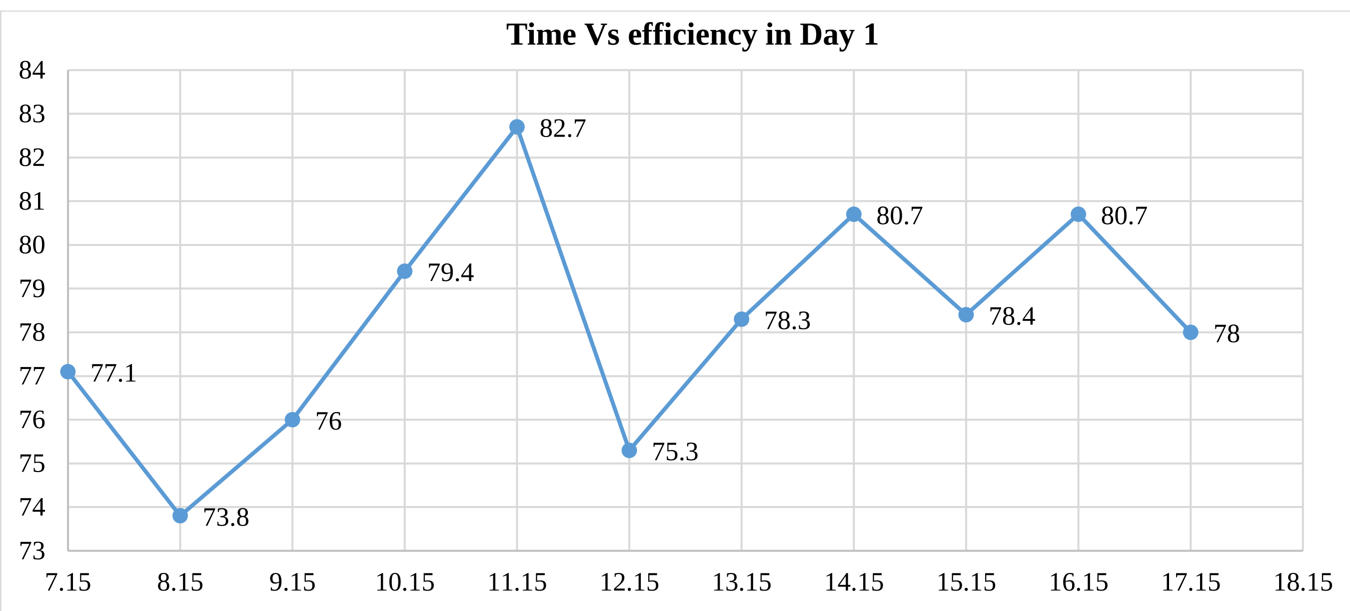
	15.15	700.6	32.2	37.7	42.8	0.784305	78.4
	16.15	560.3	31.5	33.2	37.4	0.807633	80.7
	17.15	400.4	30.8	32.8	35.7	0.780349	78.0
						Avg	78.2

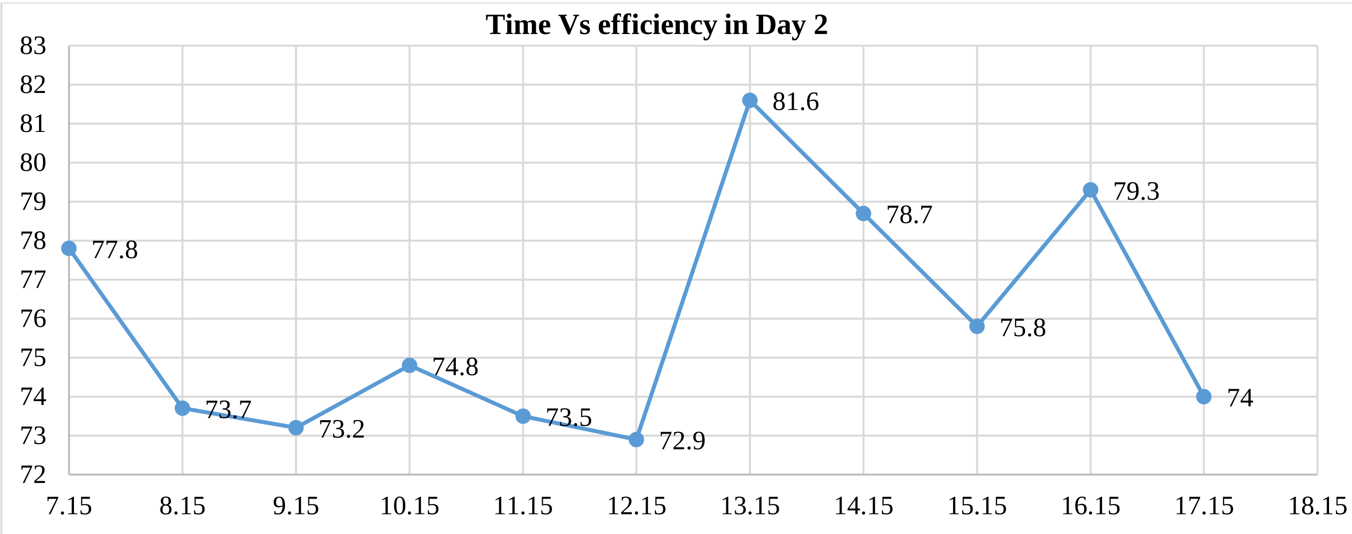
Table 8. Various temperatures and the efficiency of solar collector (Day 2)

	Time	**G_b in W/m^2**	**T_{am} In C**	**T_{in} in C**	**T_{out}**	**Drying Efficiency**	**% Drying Efficiency %η**
Day 2	7.15	650.2	28.2	33.3	38	0.778818	77.8
	8.15	700.8	29.3	33.8	38.6	0.737959	73.7
	9.15	750.6	30.3	34.5	39.6	0.73206	73.2
	10.15	820.3	34.1	35.8	41.5	0.748665	74.8
	11.15	820.5	34.2	38.4	44	0.735351	73.5
	12.15	900.4	35	39.3	45.4	0.729927	72.9
	13.15	870.5	35.1	39.8	46.4	0.816884	81.6
	14.15	820.6	34.3	39.5	45.5	0.78778	78.7
	15.15	710.2	32.3	36.5	41.5	0.758533	75.8
	16.15	570.1	31.2	34.6	38.8	0.793749	79.3
	17.15	450.8	30.8	33.8	36.9	0.740906	74.0
						Avg	75.9

Table 9. Various temperatures and the efficiency of solar collector (Day 3)

	Time	**G_b in W/m^2**	**T_{am} In C**	**T_{in} in C**	**T_{out}**	**Drying Efficiency**	**% Drying Efficiency %η**
Day 3	7.15	660.4	29.2	32.3	37.2	0.799419	79.9
	8.15	720.5	29.3	33.0	38.2	0.777597	77.7
	9.15	750.6	30.5	34.5	40.4	0.846893	84.6
	10.15	810.3	32.1	35.3	41.8	0.864277	86.4
	11.15	830.5	34.2	38.3	44.3	0.778389	77.8
	12.15	920.6	35.6	39	46	0.819242	81.9
	13.15	860.6	35.8	39.2	45.4	0.776203	77.6
	14.15	830.3	34.2	39	45.2	0.804529	80.4
	15.15	720.2	32.3	36.2	41.4	0.777921	77.7
	16.15	580.4	31.3	34.2	38.4	0.779663	77.9
	17.15	460.8	30.9	33.2	36.4	0.748209	74.8
						Avg	79.7





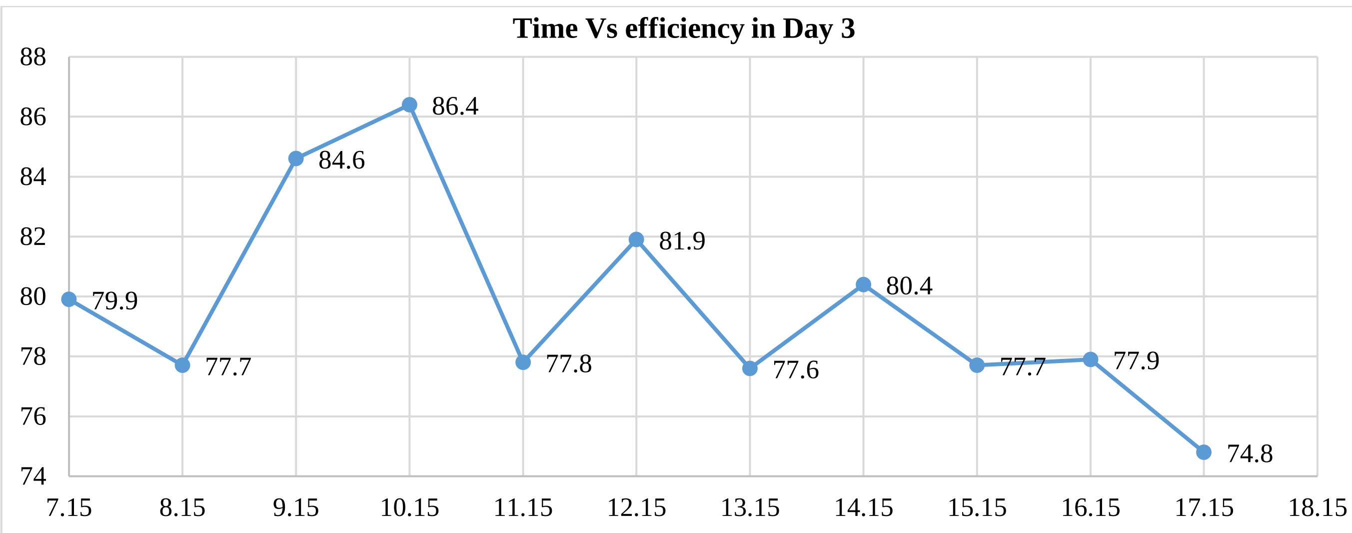
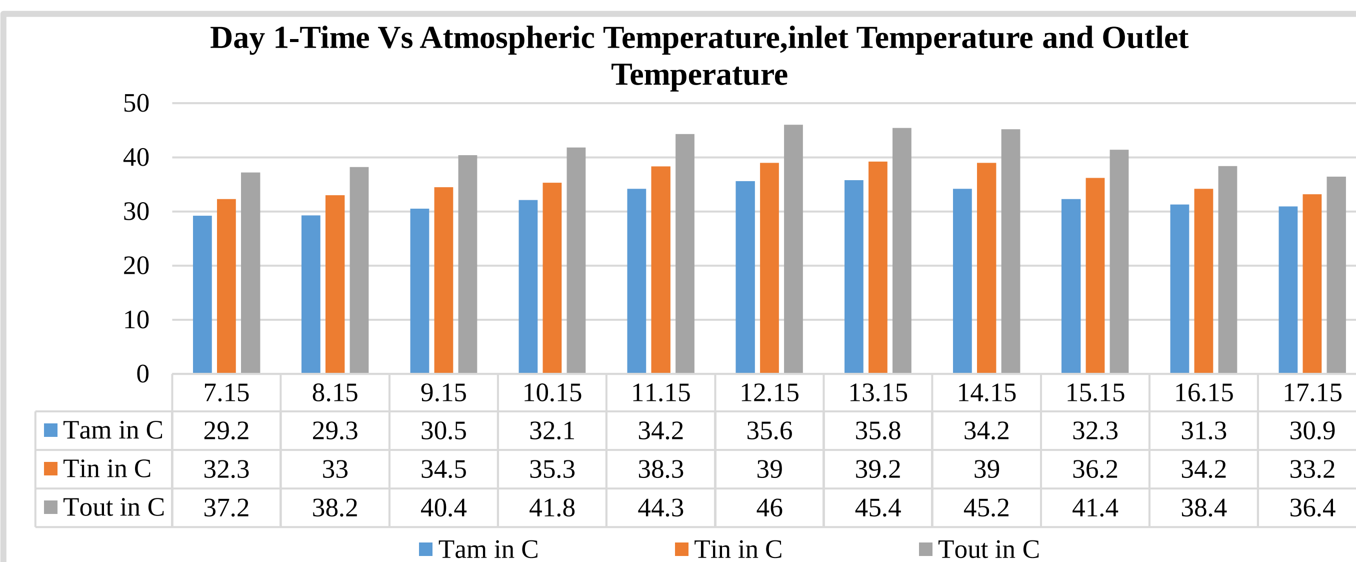
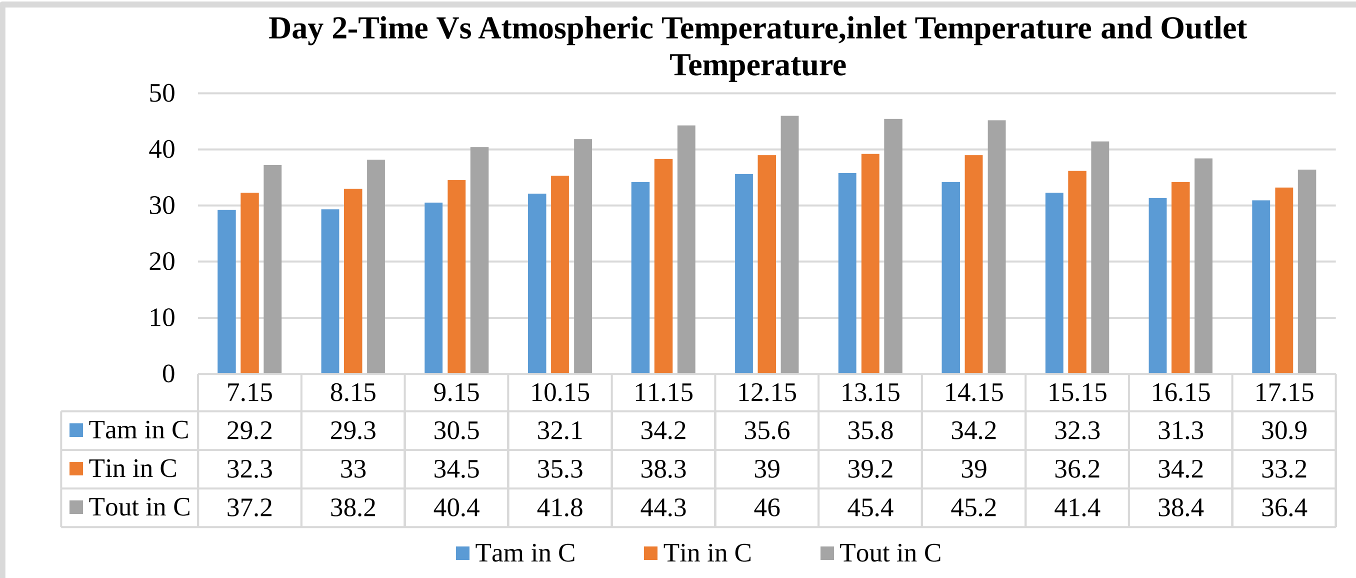


Fig. 15 Time Vs. Efficiency Analysis Day 1, Day 2, and Day 3





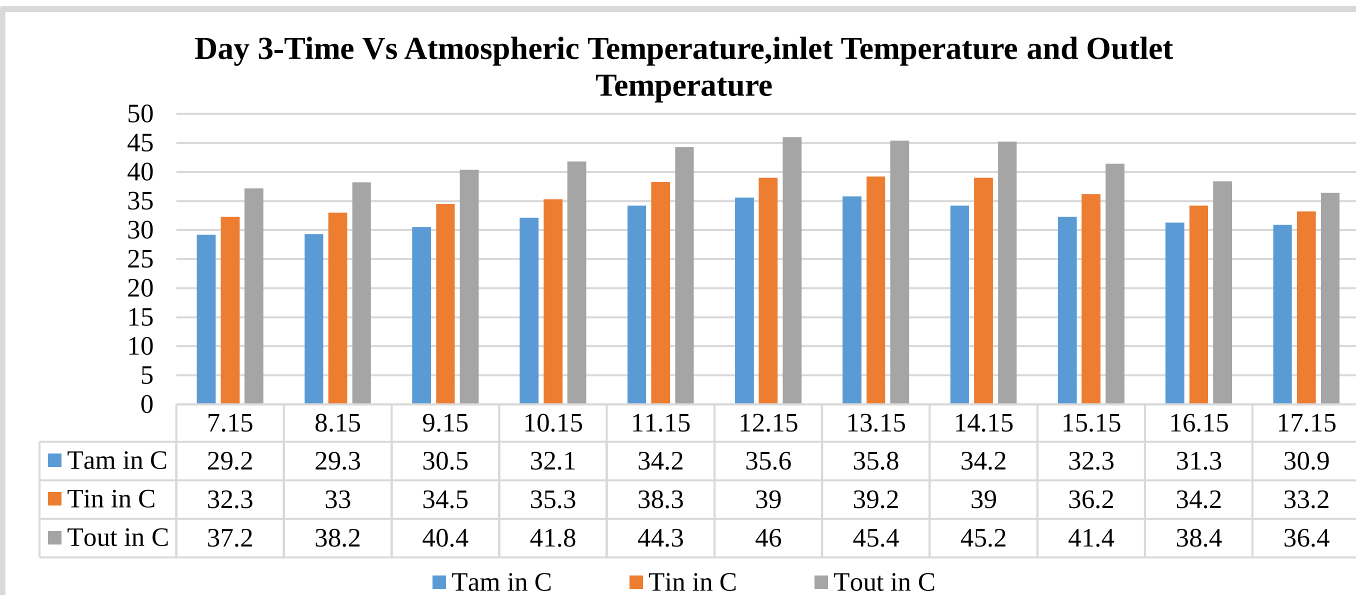


Fig. 16 Various recorded temperatures during the drying process

7. Economic Analysis of the Proposed Solar Dryer

Cost analysis involves different costs, such as capital cost, annual maintenance cost, repair cost, return on investment, and estimated savings. The capital cost involved is as follows. Capital cost = Design cost + Material cost + Labour cost+ Production costfDesign cost involves the time value for the designer and software cost, which is a one-time investment in the proposed methodology. Material cost involves Aluminum sheets and cast-iron rods for stands and paints. In the project, some mechanical devices, such as a cutter and welding machine, were used and rented. Labor costs are involved in the development of solar dryers. The cost estimation is as follows. Capital cost = 20+300+50+50 = OMR 420 [OMR=Omani Rials]. Compared to many solar dryers, the proposed one is cheap and effective. It is maintenance-free, and the annual maintenance cost will be zero.

The repair will only be in the evacuated copper tube, which will not exceed OMR 50. So, this cost is affordable for Omani fishermen, and the rate of return can be acquired within a year because there is no electricity or fuel involved in operating the dryer.

According to World Meter, Oman's CO2 emissions per capita are equivalent to 20.36 tons per person (based on a population of 4,730,226 in 2022) [20].CO2 emissions increased by 3.02% over the previous year, representing an increase of 2,684,790 tons over 2021, when CO2 emissions were 88,964,290 tons. It is time to reduce carbon dioxide emissions in Oman to improve the environment. So, the solar-based solution will be crucial in reducing Oman's carbon footprint and improving green energy utilization.

8. Conclusion and Recommendations

Since the Sultanate of Oman has more sunlight during the daytime, it is possible to dry the fish as soon as possible compared to other countries. If so, it is possible to dry the fish, improving fishermen's lifestyle. The electrical power requirement for the drying process is zero, so the suggested dryer is very economical. Also, it is possible to generate electricity from the sun and change this process to an electrical-based solar dryer. If so, we can adjust the temperature at any time, and it is even possible to use it at night for the drying process in hybrid mode. Since Oman has a better chance to improve the fishery sector, this drying process will help save fish and make it possible to export a lot to nearby nations where the demand for drying fish is higher. So, all of the analyses show that the effectiveness of the solar drying method is high compared to the traditional drying methodology.

The main objective of this project is the development of a solar dryer to provide sufficient heat under given humidity to dry fish, which will be wasted in the fishery sector of the Sultanate of Oman. It increases the vapor pressure of the moisture confined within the product. It decreases the relative humidity of the drying air so that the moisture-carrying capacity of the air can be increased, as per the statistical study in this work. In conclusion, the. Solar dryers can be an effective method of drying fish, and they also reduce environmental carbon emissions as a long-term benefit. The solar dryer serves a green climate compared to the electrical-based methodology in the fish-drying industries. Technical guidance in designing solar-assisted systems is essential for high-performance advanced energy utilization systems and long-life drying systems. The collector efficiency obtained from the proposed method is 77.9, and the overall drying efficiency is 33.1%. Obayopo, S.O and Alonge,O.I obtained collector efficiency in solar dryers for fish, which is 74%[21]. Al Kayiem, H., Yassen, T.A., and Al Azawiey, S. obtained mean and overall efficiency in a hybrid thermal drying system of 13%[22]. Nugrahani, E.F et al. obtained 34.94% efficiency in Gresik, Indonesia. Compared to these research works, the results obtained in the proposed methodology show promising results regarding collector and overall dryer efficiency. The reason behind this efficiency is the automatic tracking mechanism. Without a tracking mechanism, the efficiency obtained for solar collectors was 48.2%, and the overall drying efficiency was 24.5% [23].

This technology can be adapted to dry agricultural products like dates, vegetables, and cereals. This can be adopted throughout the year in the Sultanate of Oman because of the availability of the sun's rays. If the quantity of fish or vegetable products is higher, it is possible to use a Scheffler-type parabolic concentrator for drying [24]. The main problems for solar-based drying are dust, rain, and cloudy weather. Therefore, dust-free drying areas are required. Whenever there is a threat of a dust storm or rain, the drying structure should be closed with a waterproof cover, which is mandatory in this proposed methodology.

There is a possibility of improving the proposed design with

1. Backup method using electricity
2. Batteries to operate at nighttime
3. Automatic cover during the rainy season
4. Automatic dust cleaning method
5. Continuous monitoring of moisture content in the drying fish

Overall, the solar dryer is an effective method that will be very useful in the future in the Sultanate of Oman. Since the country focuses on diversified areas to improve its economy, the fishery sector will have more potential to contribute to its growth [25]. So, many modern techniques are needed in this sector, and as researchers, we believe Scheffler dryers are one of the areas that require more concentration for future development. It is faster and more reliable than the normal process.

Similarly, drying dry grapes, pineapples, and dates will take less time than the standard dry process. Since it is natural, there is no nutritional value, taste, or quality reduction. So, this methodology is more reliable for drying fish. In the future, a big-sized parabolic collector and a particular device for the stand will help to go faster than the methodology developed in this work.

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