Development of a Solar Energy operated Fish dehydrator for the livelihood security of fisherwomen of South Odisha

Fisherwomen traditionally dry fish in open, often in unhygienic conditions. It results in poor price realization from the market. Application of solar drying technology has the potential for higher value addition of fish products. Accordingly, a solar dryer has been designed and fabricated considering various system parameters such as inlet temperature of air, humidity, moisture carried by air per minute and outlet temperature of air. This dryer is being used by the fisherwomen in coastal area of south Odisha which is involved in technology based and market linked sustainable livelihood security of fisherwomen. The dryer has been designed with a capacity of 20 kg/day fish and is manufactured with aluminium sheet and SS304 grade stainless steel perforated trays. The solar drying device comprised of an enclosed means, a drying room, plurality of perforated holders for holding of drying material and a plurality for air blowing means powered by solar energy in order to provide effective removal of moisture. The perforation over the food holders is circular and the holders are spaced at an equal distance from each other within the drying room to facilitate effective air circulation. The air blowing through fan is used to increase the rate of moisture removal and circulation of heated air in the drying room. The entire drying operation takes place by means of direct solar energy falling over the dryer. It was delivered at Markondi village almost 30 KM from the city of Berhampur, sponsored by Voluntary Integration for Education and Welfare of Society (VIEWS), a development organisation working for the livelihood security of fisherwomen of South Odisha.

Nomenclature

M_w =Mass of water to be removed

M_p = Mass of product

M_i = Initial water content in percentage

M_f = Final water content in percentage

ϕ = Relative humidity

P_v = Partial pressure of water vapour

P_{vs} = Partial pressure of water vapour when the air is fully saturated

P_t = Atmospheric pressure

W_1 = Specific humidity at inlet of dryer

W_2 = Specific humidity at outlet of dryer

m_a = Mass of dry air in kg/hr

m_v = Mass of water vapour

N = RPM of fan

V_a = Volume of dry air

V_v = Volume of water vapour

v_1 = Velocity of air inside the chamber

v_2 = Velocity of the air at the outlet

$\dot{V}$ = Volume flow rate

d = Diameter of the fan

A_1 = Transverse cross section area of dryer

A_2 = Area of circular hole at outlet

ω = Angular velocity

L = Length of the dryer

b = Width of the dryer

1. Introduction

Fisherwomen traditionally dry fish in open, often in unhygienic conditions. It results in poor price realization from the market. Application of solar drying technology has the potential for higher value addition to food products. Solar drying technology involves exposing food to sunlight, while air flowing past the food to remove the moisture content from the food naturally. The warmer the air, the more moisture it can remove from the food. The present invention relates to an improved solar dryer with improved air movement and warmth increasing the drying efficiency. We need a more simplified, easy to use, economic and small scale direct solar dryer, which can utilize solar energy for drying food as well as for powering of air blowing units. A drying means which utilize all three modes of heat transfer, conduction, convection and radiation for enhanced drying to take place. The design needs to affordable by the fishers for a better hygienic way of drying food, thereby increasing the market value for their effort.

1.1 Rationale of the study

Fisherwomen in coastal area find it difficult to produce dried fish in a hygienic way. Exiting methods available are expensive (electric drying), unreliable (electricity is not available all the time) and unhygienic (open sun drying). Given the availability of rich solar energy for more than 80 percentage days in a year in coastal area of Odisha, it can be used for drying fish. Hence the present attempt will help fisherwomen in adding higher value to their fish product and in the process getting higher profit.

1.2. Objectives of Research

- The broad objective of research is to develop an energy efficient solar dryer for drying foods, vegetables, seafood. The specific objectives are

- Design a solar dryer for fish drying in coastal area of Odisha.
- Fabricate the designed dryer.
- Test and transfer the dryer to the community.

1.3. Scope

The study was for design a solar dryer for drying fish. The design can be used under similar situation.

1.4. Methodology

- Design to be done using basic concepts of heat transfer in general and dryer in particular.
- Dryer will be fabricated based on thermal and mechanical design.
- Data will be collected by drying fish to determine the good operating practices.
- Training of fisherwomen for use of dryer.

1.5. Section Plan

After the introductory section, next section was literature review. Third section covered thermal and mechanical design of dryer including bill of materials and estimated price. Fourth section covers data collection and analysis. Final sections include conclusion and recommendation.

3.1 Design calculations

For design calculations the considered dry bulb temperatures (DBT) and relative humidity (RH) at inlet and outlet are shown in figure 3.1. The parameters are considered after a brief study of atmosphere at the coastal area of south Odisha.

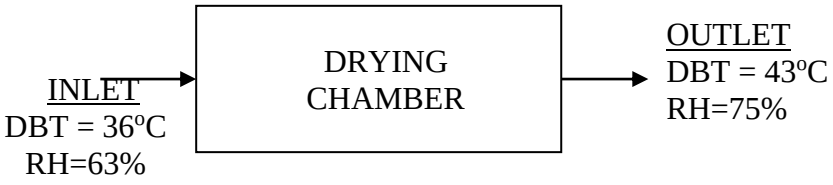


Figure 3.1. System parameters at inlet and outlet

M_p = 20 kg

M_i = 71%

M_f = 20%

$$M_w = \frac{20(0.71-0.2)}{1-0.2} = 12.75 \text{ kg of water to be removed from 20 kg of wet fish} \quad (1)$$

At DBT = 36º C, RH = 63% (At Inlet)

$$\phi = \frac{P_v}{P_{vs}}$$

$$0.63 = \frac{P_v}{0.0594} \quad (2)$$

$$P_v = 0.037471 \text{ bar}$$

$$W_1 = \frac{0.622 P_v}{P_t - P_v}$$

$$= \frac{0.622 \times 0.037471}{1.0132 - 0.037471} = 0.02387 \text{ kg of water per kg of dry air} \quad (3)$$

<u>At DBT= 43° C, RH = 75% (At Outlet)</u>

$$\phi = \frac{P_v}{P_{vs}}$$

$$0.75 = \frac{P_v}{0.08649} \quad (4)$$

$$P_v = 0.0648 \text{ bar}$$

$$W_2 = \frac{0.622 P_v}{P_t - P_v}$$

$$= \frac{0.622 \times 0.0648}{1.0132 - 0.0648} = 0.0425 \text{ kg per kg of dry air} \quad (5)$$

$$m_a = \frac{M_w}{W_2 - W_1}$$

$$m_a = \frac{12.75}{0.0425 - 0.02387} = 684.3 \text{ kg of dry air} \quad (6)$$

Assuming 10 hrs. /day (in one day to be dried)

$$m_a = \frac{684.3}{10} = 68.4 \text{ kg of dry air per hour}$$

Mass of dry air per second, $\dot{m}_a == \frac{68.4}{3600} = 0.019$ kg/sec

Volume flow rate of dry air, $\dot{V}_a = \frac{\dot{m}_a R_a T_a}{P_t - P_v}$

$$= \frac{0.01901 \times 287 \times (273 + 36)}{(1.0132 - 0.037471) \times 10^5}$$

$$= 0.01727 \text{ m}^3\text{/ sec} \quad (7)$$

$$\dot{V} = A_1 v_1 = \frac{\pi}{4} d^2 1.5 \quad (8)$$

Diameter of duct $d = 0.121$ m =121 mm

Assuming 1.5 m/sec is the velocity of air inside the chamber

$$A_1 v_1 = A_2 v_2$$

$$0.25 \times v_1 = \frac{\pi}{4} (0.121)^2 1.5$$

Velocity of air inside the chamber

$$v_1 = 0.068 \text{ m/sec}$$

Velocity of air inside the chamber = 0.068 m/sec (9)

3.2 Working principle

The system had a solar drying chamber and 10 watt solar PV panel used for operating DC fan as show in the figure (Fig. 3.2). This panel has been integrated with dryer for powering 4 no of 12V DC fan that is two induced draft fan and two forced draft fan. Further solar radiations facilitate the drying operation to take place. Solar radiations fall upon the dryer and heats up the device. The dryer comprises of an enclosed means to open and close the unit a plurality of food holding means arranged at equal distances. Provisions are made at the side walls of the dryer for a set of air blowing units powered by means of solar photovoltaic cell. Plurality of blowers according to the invention, assist in ingress and egress of air. Off the plurality of blowers at the walls of the dryer a set of blowers (forced draft fans) creates a positive pressure i.e. above the atmospheric pressure are placed at the higher side of the wall to ingress air into the unit across the food holders, while the another set of blowers (induced draft fan) are placed at the bottom of the wall of dryer to egress air out of the unit. Further the fans provide proper circulation of air within the drying room of the drying unit. According to the invention dry air is drawn into the unit by means of set of air blowing units. The dryer being made of a good heat conducting material, transfers heat to the immediate dry air within the unit via convection. The dry air gets heated with via convective transfer of heat from the hot surface of the dryer. Air blowing units; create convective air currents in the room, circulating warm air in the entire drying room. This warm air, passes across the food holders, through the perforations on the food holders, thereby drawing moisture from the food placed over the holders. The dry, warm air absorbs moisture from the food, becomes saturated moisture laden air. This saturated air is withdrawn from the unit by another set of air blowing units.

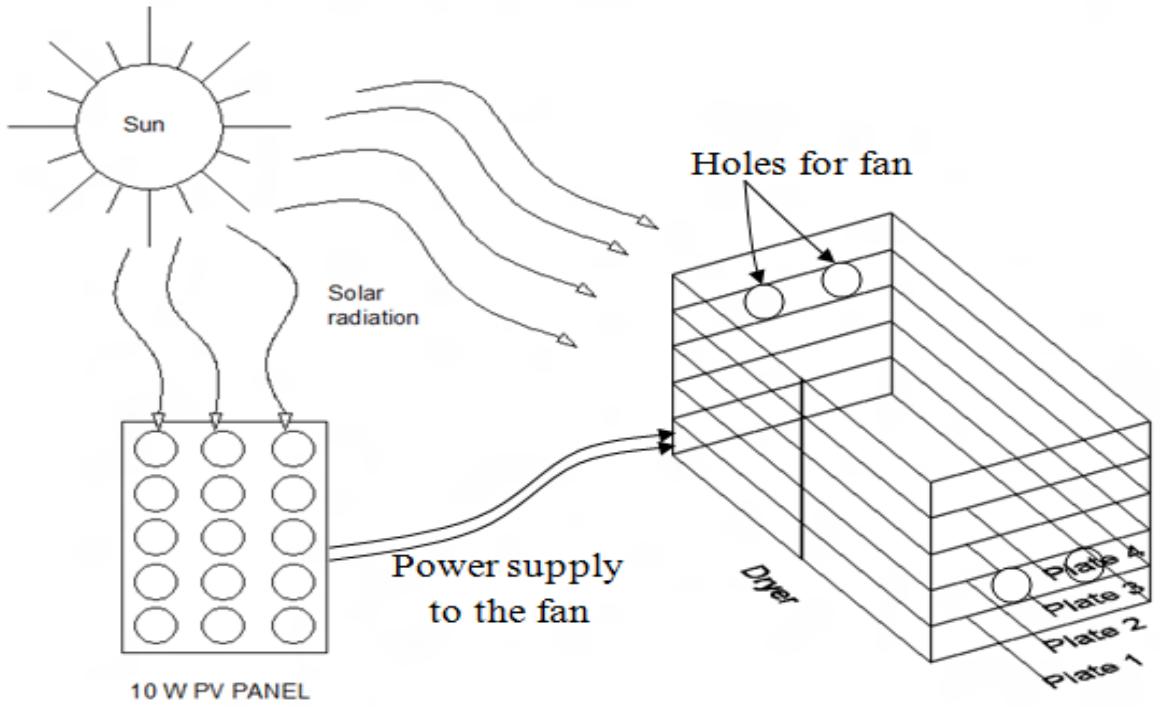


Figure 3.2. Schematic diagram of solar drying process using solar dryer

3.3 Budget (BOQ) Proposal for Solar Dryer, Capacity of 20 KG

The broad objective of this Budget proposal was to develop an affordable, reliable and high quality solar dryer to be used for drying raw fish. The prototype was developed with the help of Aluminium sheets, S.S. Bolts, L-Angles (Specification given). The total prototype constitute of three broad things

1) Aluminium sheets cut as per the dimension in the m/c.

2) Sheets bent as per the dimension and trays will be manufactured and bend.
3) Sheet was to be drilled as per the dimension and will be joined by Bolt and Nut joints.
4) Trays were drilled for proper airflow, 12V DC fans are to be fixed in sideways for proper airflow into the system and black paint will be applied all over the body.

Table 3.1: Bill of Materials and Estimated Price.

Item no	**Description of item**	**Unit**	**Quantity**	**Total**	**Total Cost**
1	Aluminium sheets	Sq.	Length=1000 mm, Width=1000 mm, Height= 500mm	27 Sq.	12000/-
2	Tray will be made of Al	Sq.	980mm x 480mm	5.06 Sq.	6500/-
3	S.S. Bolts	Nos	M6/10mm	50nos	500/-
4	NUTS	Nos	M4/10mm	30nos	500/-
5	NUTS	Nos	M3/10mm	12nos	500/-
6	L-Angle for Foot Support	Nos	L-Angle	4nos	500/-
7	Red-Oxide	--	0.5 L	--	500/-
8	Solar Panel	PC	60W, 12VDC	--	3000/-
9	Fans	PC	12V DC Fan	4nos	5000/-
10	Copper Wires	m	5 m	--	1000/-
				Total	**30000/-**

Fabrication process:

The dryer has been fabricated with the help of aluminium sheets, S.S. Bolts, Angle bars. The various parts of the dryer have been fabricated by various processes. The fabrication is explained below.

Sheet Metal Cutting: Sheets are cut to the dimension of top and bottom frame, side frame, back supporting frame and four trays by shearing process. The frames are joined by riveting process. Since Aluminum welding process is not available here. To fix the 12V DC fan four holes of diameter 120 mm are made by drilling process. These fans are fixed in sideways for proper airflow into the system. Trays are perforated for proper airflow and placed inside the dryer at equal space. To keep the trays the angle bars are fixed on the side frame of the dryer. The fabrication of different parts of dryer is shown in figure 3.3. The figure 3.4 shows the complete dryer and the solar panel.

Figure 3.3. Fabrication of different parts of solar dryer by various processes

Figure 3.4. Installation of solar Dryer for the livelihood security of fisherwomen of South Odisha

3.4. Installation of Photo Voltaic panel

The figure 3.8 shows the solar tracking frame which was installed in order to make the module facing towards the sun at all times. Because the amount of sunlight hitting the array also varies with the times of days because of the sun's movement across the sky. As the Gopalpur latitude is $19^0 18' 13.44"N/84^0 57' 52.72"E$, the panel was tilted 19^0 facing towards south.

Figure 3.5. Shows the installation of PV panel

4. Data Collection and Discussion

In this chapter the experiments on the solar dryer had been conducted. 20 kg of different types of fishes have been taken for the experiment.

4.1. Inside Temperature of Dryer

To measure the inside temperature, the dryer is kept in a open field so that the dryer can be exposed to sun ray. The variuos parameters required for experiment has been show in the figure 4.1.The experiment is started at 9 am and at every one hour interval the inside temperatures are measured by non-contact type pyrometer. The temperatures obtained from the experiment are shown in the table 4.2.

Table 4.1. Various Parameters Considered for Experiment.

Name of the Product	Fish (Kana Katha) - Indian Mackerel
Zoological Name	Rastrelliger Kanagutra
Date of Drying	17.05.2015 to 19.05.2015
Starting Hour	9.00 am
Ending Hour	4.00 pm
Total Weight Before Drying	4000 gm.
Weight of the fish tested in solar dryer	2000 gm.
Weight of the fish tested in Traditional Direct Sunlight drying	2000 gm.

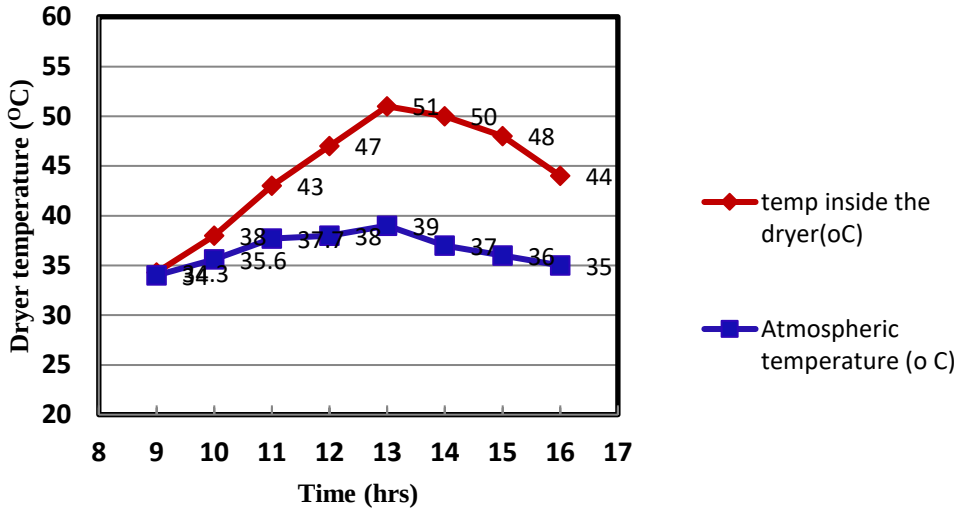
From the table 4.2 it has been observed that the inside temperature of the solar dryer increases with time, up to 2 pm and then decreases. It happens due to the increase of sun ray and the black coating on the solar dryer. Due to increase in temperature the moisture carrying capacity of the air increases and accordingly the performance of the dryer increases. With increase in temperature of air the pressure increases and the dry and warm air absorb moisture from food, become saturated moisture air. The saturated air is withdrawn from the drying chamber by another set of fans. The dryer being made of a good heat conducting material, transfers heat to the immediate dry air within the unit via convection. The dry air gets heated with via convective transfer of heat from the hot surface of the dryer. Air blowing units; create convective air currents in the room, circulating warm air in the entire drying room. This warm air, passes across the food holders, through the perforations on the food holders, thereby drawing moisture from the food placed over the holders. The temperature variations are shown in figures 4.1 to 4.3.

Table 4.2. Inside temperature of the solar dryer

Day / Time		9 am	10 am	11 am	12 Noon	1 pm	2 pm	3 pm	4 pm
17.05.15	Temp inside the Dryer	34.3° C	38°C	43°C	47°C	51°C	50° C	48° C	44°C
	Atm. Temp	34°C	35.6° C	37.7° C	38°C	39°C	37° C	36° C	35°C
18.05.15	Temp inside the Dryer	36°C	38°C	42.7° C	47.7° C	54°C	50° C	48° C	40°C

	Atm. Temp	35°C	36°C	38°C	40°C	39°C	37° C	34° C	33°C
19.05.15	Temp inside the Dryer	37°C	40°C	44.7° C	50°C	55°C	48° C	46° C	44°C
	Atm. Temp	36°C	38°C	39°C	40°C	39.5° C	38° C	37° C	35°C

Figure 4.1. Temperature measurement in °C inside the dryer on the date of 17.05.2015



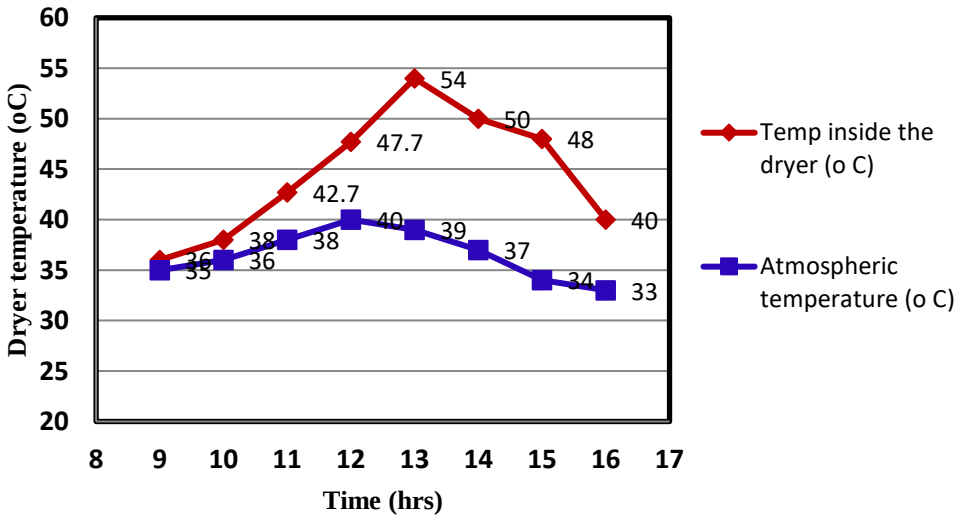


Figure 4.2. Temperature measurement in °C inside the dryer as on date 18.05.15

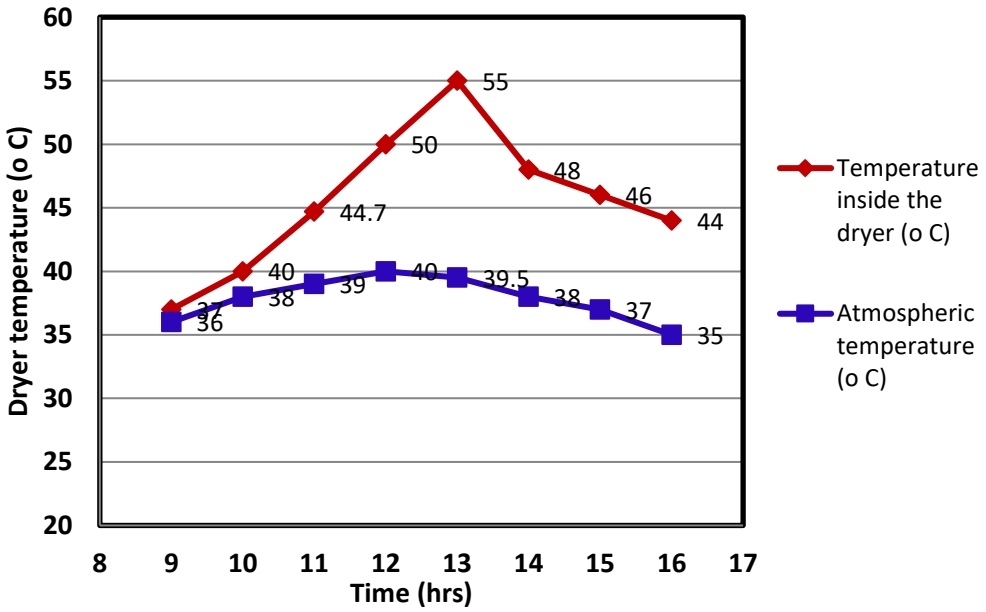


Figure 4.3. Temperature measurement in ^{o}C inside the dryer as on date 19.05.2015

4.2. Temperature variation in Four Trays

To measure the inside tray temperature, the dryer is kept in a open field so that the dryer can be exposed to sun ray. For the experiment the considered parameters are presented in the table 4.3. The experiment is started at 9 am and at every one hour interval the inside four trays temperatures are measured by non-contact type pyrometer. The temperatures obtained from the experiment are shown in the table 4.3. It has been found that there is a small variation in temperature from tray 1 to tray 4 as per the thermodynamics second law heat always flow from higher temperature to lower temperature. The temperature variations are shown in figures 4.4 to 4.6.

Table 4.3. Different Temperature of Different Trays

Day/ Time	Time	Temp in tray 1 (°C)	Temp in tray 2 (°C)	Temp in tray 3 (°C)	Temp in tray 4 (°C)	Day/ Time	Time	Temp in tray 1 (°C)	Temp in tray 2 (°C)	Tem in tray 3 (°C)	Temp in tray 4 (°C)	Day/ Time	Time	Temp in tray 1 (°C)	Temp in tray 2 (°C)	Temp in tray 3 (°C)	Temp in tray 4 (°C)
am	9	34.3	33	32.7	32.3	am	9	35.9	35.5	35	34.7	am	9	37.1	36.5	36	35.4
	10	37.5	36.3	35.3	34.5		10	37.8	37.5	37	36.5		10	40	39.5	38.9	38.4
	11	42.8	42.1	41.5	41		11	42.3	41.7	41	40.7		11	44.7	44	43.5	43
	12	46.9	46.5	46	45.5		12	47.5	47	46.7	46.5		12	49.9	49.4	48.9	48.1
pm	13	50.8	50.5	50.1	49.5	pm	13	53.8	53	52.7	52.1	pm	13	54.9	54.6	54.1	53.8
	14	49.8	49.5	49	48.7		14	49	49	48.7	48.4		14	47.9	47.5	47	46.6
	15	47.7	47.1	46.5	45.7		15	47.1	47.1	46.5	46		15	46	45.5	45	44.6
	16	43.9	43.5	43	42.7		16	39.5	39.5	39	38.6		16	43.9	43.2	42.7	42

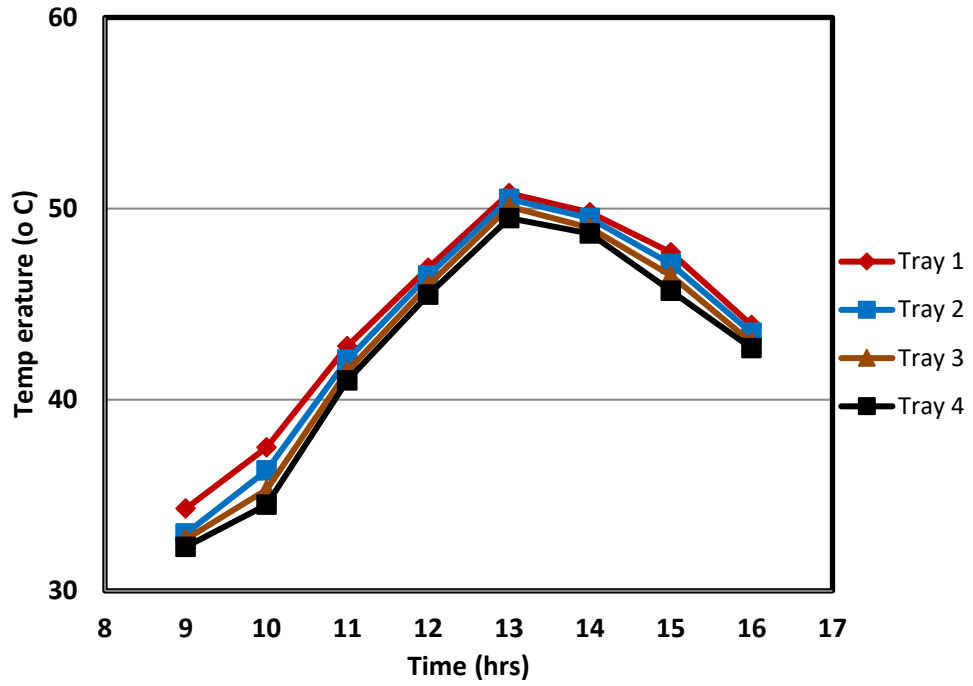


Figure 4.4. Temperature of Different trays on date of 17.05.15

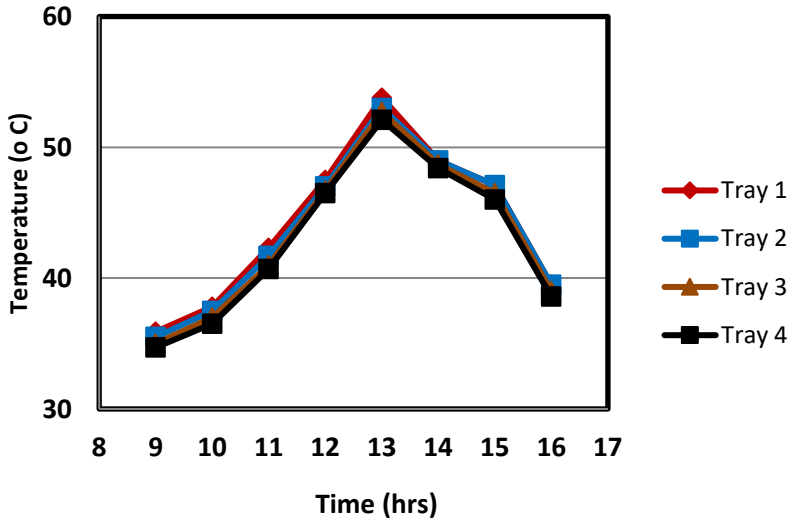


Figure 4.5. Different temperature of trays on date of 18.05.15

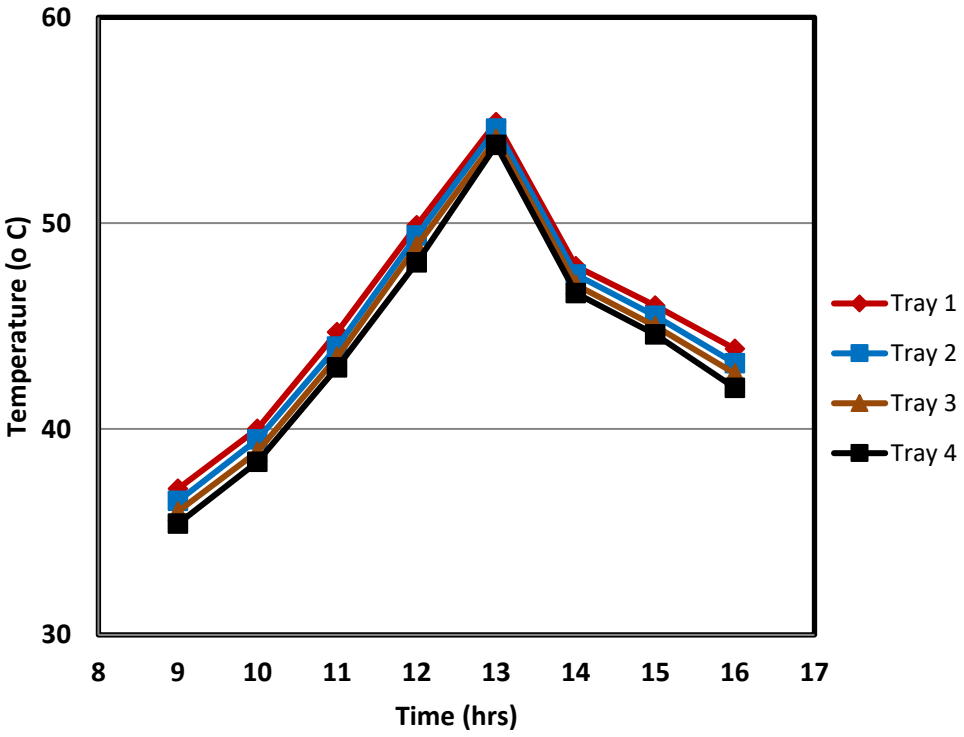


Figure 4.6. Different temperature of trays on date of 19.05.15

4.3. Testing of Dryer

To study the performance of the dryer varieties of fishes have been dried. The figure 4.7 shows the drying of fish in the solar dryer. The table 4.3 shows the comparison of weight reduction of fish dried in open sunlight and dried in solar dryer. It can be seen that the percentage of weight reduction is more in case of dryer with a less time.

Table 4.4. Weight of fish before and after drying:

Fish	**Initial Weight (gm.)**	**Final Weight (gm.)**	**Time Taken (Hrs.)**	**Weight Reduction %**
Dried in Open Sunlight	2000	903.24	56	54.8
Dried in Solar Dryer	2000	757.9	21	62.01

Figure. Varieties of fishes during drying operation

Conclusions and Scope for Future Work

Solar dryer according to the design eliminates unhygienic traditional way of drying food in open lands receptive to contaminants. Further the enhanced dryer, eliminates large place for drying, further being provided with holders that has enough capacity for large amounts of food to be dried. The enhanced solar dryer improves drying efficiency resulting in increased market value to the products. Convectional method of drying small prawns has a market value of 350 INR per kg while the solar dried prawns' sale has 70% edge over conventional methods pricing up to 450 INR. Solar drying technology involves exposing food to sunlight, while air flowing past the food to remove the moisture content from the food naturally. The warmer the air, the more moisture it can remove from the food. The solar dryer of the present invention facilitates quick drying of the material to be dried. It can be seen that the percentage of weight reduction is more in case of dryer with a less time as compare with the fish dried in open sunlight. The temperature inside the drying chamber increases up to 51^{O} C while the atmospheric temperature is 34^{O} C so that the efficiency of the dryer increases.

5.2 Scope for Future Work

The scope of the present invention is not only limited to any particular industry and it can be applied or used in any other system within the spirit of the invention.

- The solar dryer made of a heat conducting material may be commercial grade aluminium. The dimensions of the solar dryer may be of length: 1000mm, breadth: 500mm, height: 500mm, but is not limited.
- The shape of the solar dryer is not limited to a rectangular shape while it can be of any geometrical shape as long as the process detailed in the invention remains the same.
- The speed of the air blowing units may be varied to enhance drying operation. The number of blowers can be varied according to the drying requirements.
- The capacity of the solar panel used can be of any wattage that is sufficient to power the blowers.
- In this exemplary embodiment we have done only temperature analysis. In future we can do the various parameters (relative humidity, mass flow rate etc.) analysis.
- We can modify the solar dryer design. Here we are using the solar panel which converts the solar radiation to heat energy. In future we can design solar collector (which consists of transparent plate, absorbing plate and insulation) to generate the heat in place of solar panel.
- Here we have tested the variety of fishes only. In future we can take vegetables and fruits to be dried. The capacity of the solar dryer (20 kg per day) can be increased by modifying the design of solar dryer.