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Full Length Research Paper

Low cost solar dryer for fish

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Prawns (Kolambi) were selected as drying material in low cost solar dryer (LCSD). Time required for reducing the moisture content from 75 to 16% were observed in open sun drying and solar drying for its comparison. Salted fish inside the dryer required 8 h in order to dry prawns up to 16.15% while unsalted fish required 15 h to reach moisture content up to 15.15% in open condition. Overall collection efficiency was found as 70.97%. Average drying efficiency for salted fish was 14% and unsalted fish was 11% whereas pickup efficiency for salted and unsalted fish was found as 10 and 9% respectively. Salted prawns were found most liked for its colour and texture than unsalted solar dried sample in sensory evaluation. Unsalted prawns sample dried in solar dryer was overall accepted, while traditionally open sun dried sample was least liked for its colour and texture. The value of F is calculated as 1.98 during the sensory evaluation. The economic cost of solar dryer was compared with mechanical drying for beneficial to local fishermen. The cost of LCSD in Rs. 1700/- is affordable to poor fisherman comparing to other costly mechanical dryer. Local fisherman could recover solar dryer cost within the period of 0.19 years by adopting solar drying technology.

Key words: Collection efficiency, system drying efficiency, pick-up efficiency, economics.

INTRODUCTION

Total production of fish in Konkan region of Maharashtra is 3.5 lakh tones per year out of that, nearly 30% are dried and sold as a dried food in the market mostly during the off-season from June to September. Solar energy in Konkan region was available for 8 to 9 months in a year with average sunshine hours ranging from 6.5 to 8 h per day. The average solar energy ranged between 450 - 500 W/m^2-day (Mani and Rangarajan 1980). The average lowest temperature for Konkan region was 15°C and average highest temperature was 35°C. At present various types of fish such as Ribbon fish/Bala (*Trichiurus*), Golden anchovies/Mandeli (*Coilia dussumieri*), Croker/Dhoma (*Johnius dussumieri*), Prawns/Kolambi (*Penaeusmondon*), Paplet (*Pampus argenteus*), Surmai (*Scomberomorus guttatus*) etc. are used for drying due to their availability and good market value. Fish is a highly perishable food product and can be stored only by proper refrigeration or drying. Since most of the fishermen and gardener living at the coastal belt and hilly region are below the poverty line therefore refrigeration is distinct dream to them. The only alternative available is drying (Senadeera et al., 2003), which is the most important techniques of food preservation (Menon and Muzumdar, 1987). To reduce the processing losses during the drying and to retain the quality of dried product, it is necessary to dry the fish in the close chamber with preventing product from dust, insect, larva, birds and animal (Figure 1). By keeping importance of fish drying in region, low cost rotary solar dryer was developed to carry out solar drying study.

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MATERIALS AND METHODS

Construction of low cost dryer

The low cost solar dryer was design to dry commodities under hot and humid conditions prevailing in Konkan region of Maharashtra where most of the agricultural products need drying. This dryer can be rotated from all sides for easy loading and unloading the material.

Dryer (Figure 2) having a size 92 cm x 75 cm was made by locally available bamboo, which consist of three main parts, collector, drying chamber and inlet and outlet openings. Drying chamber designed in such way that it consist 16 trays of 70 cm x 50 cm size. Mosquito net was used for trays as it betters performance in humid region. Capacity of each tray is 0.6 kg. UV stabilized 200 micron plastic film was used for collection of solar energy. This film

Figure 1. Traditional system of fish drying.

Figure 2. Vertical rotary low cost solar dryer.

surrounded around the drying chamber and fixed by Velcro strip. Bottom and topside of the dryer was provided with openings for air circulation. Total cost of this dryer was Rs. 1700/-.

Measurements

Total solar irradiation measured by using micro control based, liquid crystal solarimeter. The temperature and humidity at different location inside the drying chamber and outside environment was measured with thermocouple via a 8 channel dataloger (DataLog ver.v 81). In order to measure reading at a different point of air column through top and bottom of drying bed, temperature sensor were set at inlet and outlet as well as mid position of drying chamber. Airflow rate along the drying chamber was calculated by measuring the velocity of exist air at top opening through an anemometer.

Moisture content

The percentage moisture content was determined by using the following formula, (Ranganna, 1986).

$$\text{M.C.(w.b.)}\ \% = \frac{(\text{W}_1 - \text{W}_2)}{\text{W}_1} \times 100$$

$$\text{M.C.(d.b.)}\ \% = \frac{(\text{W}_1 - \text{W}_2)}{\text{W}_2} \times 100$$

Where, W_1= weight of sample before drying, gram
W_2= weight of bone dried sample, gram.

Drying rate

The drying rate (g/h/100g of bone dry weight) of fish sample during drying period was determined as follows,

$$\text{Drying rate (D.R.)} = \frac{\Delta \text{W}}{\Delta \text{T}}$$

Where, ΔW = weight loss in one hour interval (g/100g of bone dry wt)
ΔT= difference in time reading (h)

The drying was carried out by loading the weighted fish in dryer from morning 8:00 am to 17:00 pm. The Fish were dried up to the final moisture content of (Malviya and Gupta, 1985) 16% (w.b.). Similar procedure was adopted for drying of fish sample in open sun drying. The drying time required for drying the fish sample from IMC to 19% (wb) in solar dryer and under open sun drying condition was critically observed.

Moisture ratio

The Moisture ratio of prawns was computed by using the initial moisture content (IMC) and equilibrium moisture content (EMC)

$$MoistureRa\,tio = \frac{(M - M_e)}{(M_o - M_e)}$$

Where, M = Moisture content (d.b.), %
M_e = EMC, (d.b), %
M_0 = IMC, (d.b), %

The EMC for fish was considered as 16% (w.b.). Drying tests of fish sample under solar dryer and open sun conditions was carried out.

Weight measurement

Moisture removal rate was calculated by taking 1000 g samples among the commodities. These samples were measured using weight balance with accuracy up to ten milligram.

No load test and load test

Dryer was tested with no load test for the thermal profile , which

Table 1. Nine point Hedonic scale for Sensory evolution

Grade	Score	Grade	Score
Like extremely	9	Dislike slightly	4
Like very much	8	Dislike moderately	3
Like moderately	7	Dislike very much	2
Like slightly	6	Dislike extremely	1
Neither like nor dislike	5		

could be suitable for drying of fish. As per the thermal ingredients, collection efficiency of dryer was calculated. The purpose of load test is to calculate the time required in drying the commodities as well as to find out the system drying efficiency and pick up efficiency of dryer.

Sensory evaluation

Sensory evolution of different organoleptic properties of the dried fish namely colour, texture and overall acceptability was carried out by a panel of 10 judges of different age groups on the basis of 9 point Hedonic scale (Rangaswamy, 2002) explain Table 1..

The ranks were determined from the scores given by the judges. On the basis of ranks, Friedman's test was conducted and value of 'F' was calculated by the following formula,

$$F = \frac{(b-1)\left[B - \frac{bn(n+1)^2}{4}\right]}{E}$$

Where, b = number of judges, n = number of treatments, B = 1/b ΣR_j^2

$R_j = \Sigma r_{ij}$ for treatment j, $A = \Sigma\Sigma r_{ij}^2$ E = A-B

R_j = Replications of j^{th} treatments

r_{ij} = Replication of i^{th} replication of j^{th} column

The calculated 'F' values were compared with standard value to determine significance of colour, texture and overall acceptability among the treatments. From the ranks of the observations of treatments, most and least accepted treatments were pointed out as per the view of organoleptic properties.

Economic evaluation

Based on working performance of solar dryer, different direct benefits were derived. These benefits were indicators of technical feasibility of dryer. Subsequently the economics of this dryer was evaluated in terms of cost per kilogram of food through fuel backup in LCSD. Hourly benefit of rotary solar dryer was compared to conventional drying backup unit and sun drying for pay back period analysis of LCSD was made. The total costs of that of the investment spread over the entire useful life of the dryer was calculated including initial cost, depreciation, operation and maintenances, and interest.

Energy required to remove kilogram of moisture from fish in rotary solar dryer is given by No. of day effectively used for drying per year = 200 days.

Fish material dried by dryer per year = 2000 kg.
Moisture removed from 2000 kg food material by drying it from 75 to 16% moisture content.
=10 (75-16)/100-16 x 2000
= 14000 kg

Energy required to dry the food is given by (Brenidorfer et al., 1995);

$$E = m \times s \times \Delta t + m_1 L_v$$

Where, M = mass of food with water (10 kg)
s = Sp. Heat of material (0.7 Kcal / Kg°C)
Δt = Temperature difference (25°C)
L_v = Latent heat of vaporization (540 Kcal/kg)
m_1 = mass of food (3 kg).
Area as per heat required:
=10 x 1 x (50 – 25) + 7 x 540
= 1870 Kcal.

Now since in drying process, 1870 Kcal of heat is required to remove the water (moisture) from 10 kg prawn material. Therefore, total energy required to remove 14000 kg of moisture from prawns
= 14000x 1870
= 2.6×10^6 Kcal.

Now suppose this energy is supplied by mechanical dryer and efficiency of dryer is 80%. Then actual energy required = 2.6×10^6 /0.8
=3.27×10^6 kcal/ year
= $3.27 \times 10^6 \times 1.1622 \times 10^{-3}$
= 3803 kWh

RESULTS AND DISCUSSION

No load test

Analysis of temperature profile inside the dryer

Under no load condition of solar drying, radiation and temperature inside the collector were measured with time of day in the interval of 10 min were plotted. Figure 3 indicated maximum temperature observed at tray number 4 at 13 pm as 57°C while 38.7°C at 10:54 am, 41.6°C at 12:24 pm, 46.3°C at 15:04 pm, and 55.1°C at 11.14 am for tray number 1, 2, 3, and 5 respectively whereas maximum ambient temperature observed was 35.3°C at 12:54 pm and solar irradiation was 600 W/m^2 at 11:14 am. Minimum temperature was observed at the end of the day at 17:00 pm for all bottom trays. It implies in total five slots of trays inside the drying chamber, increasing profile temperature was observed from bottom tray to upper tray. Overall humidity inside the dryer was minimum as compare to outside condition. Humidity varies from 32.2 to 22.3% inside the solar dryer whereas outside humidity varies from 43.02 to 29.35% shown in Figure 4.

Collection efficiency

Collection efficiency is defined as the ratio of heat receiv-

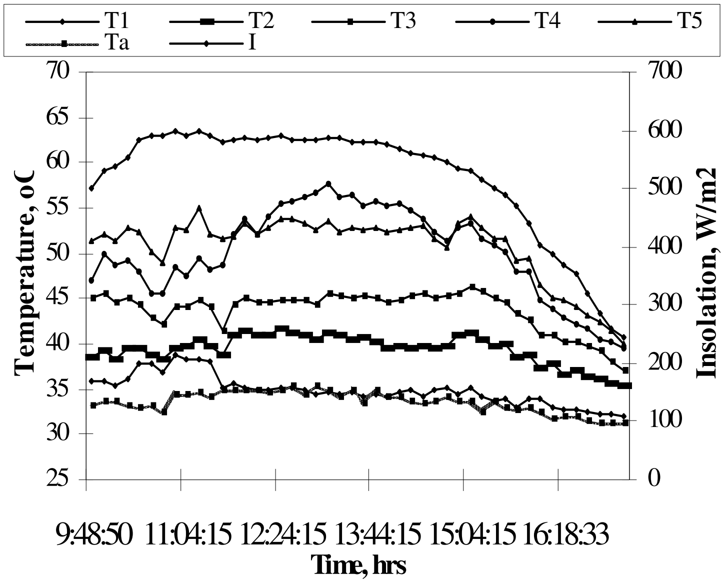

Figure 3. Thermal profile inside the solar dryer.

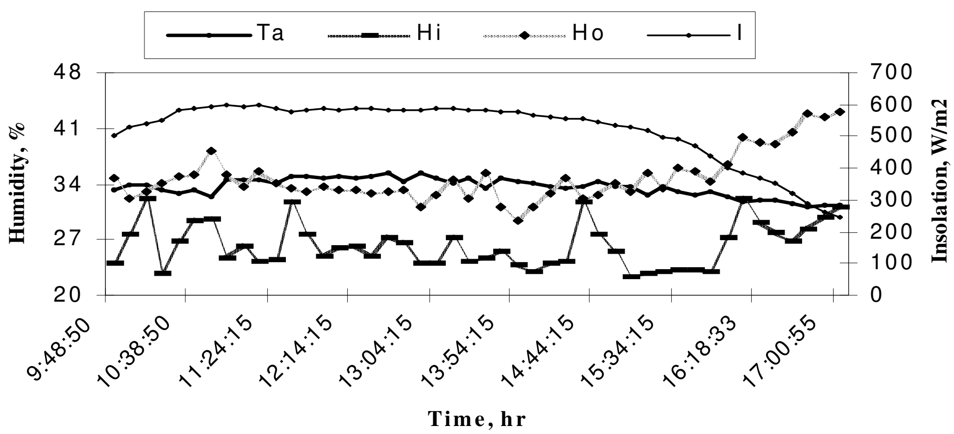

Figure 4. Variation of humidity inside the solar dryer.

ed by the drying air to the insolation upon the absorber surface and is calculated from equation (i).

$$n_c = v \times \rho \times C_p \times \Delta t \times C_p \div A_C \times I_d \quad \text{(i)}$$

Where, V= Volumetric flow rate of air (m^3S^{-1}), ρ = Air density (kgm^{-3}), ΔT= Air temperature elevation (K), Cp = Air specific heat ($Jkg^{-1}K^{-1}$), Ac= Collector area (m^2), Id= Insolation on collector surface (W/m^{-2}).

Since η_c is a assessing of the performance of collector, it was calculated using the reading for no load tests shown in Figure 5 and overall collection efficiency was found as 70.97%.

Load test

Moisture content, drying rate and moisture ratio variation

Prawns type fish were selected for load test under LCSD dryer. Initial moisture content was found to be 75.93% in laboratory test. These fish were dried up to 16% moisture content for both inside and outside condition of dryer. Time required to each condition for prawns drying was calculated. Salted fish inside the dryer required 8 h to dry prawn's up to 16.15% while unsalted fish required 15 h to reach moisture content up to 15.15% in open condition. Unsalted fish inside the dryer took slightly higher time to

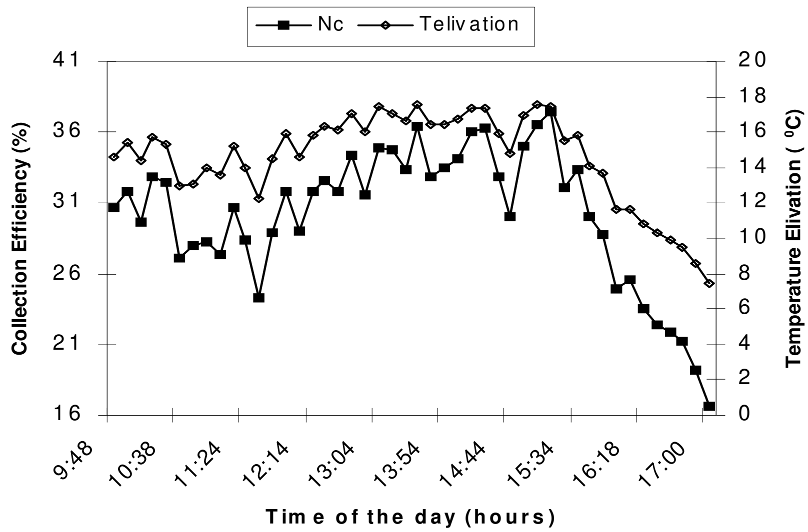

Figure 5. Variation of collection efficiency with time.

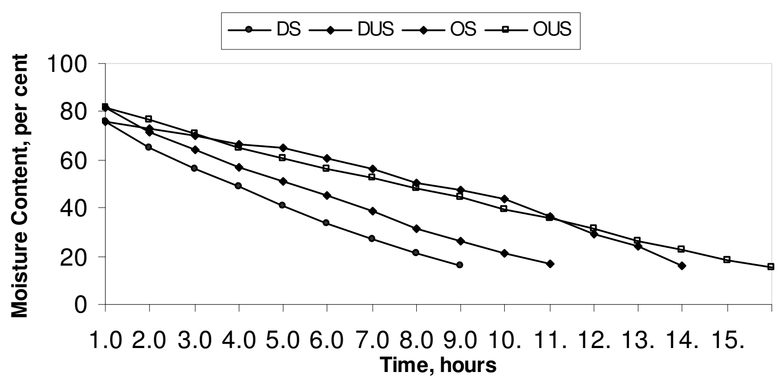

Figure 6. Variation of moisture content with time.

reach up to moisture content 16.91% whereas salted in open condition required 13 h to dry up to 16.37% shown in Figure 6. Trend observed during the fish drying inside solar dryer for drying rate and moisture ratio was depicted in Figure 7.

Drying efficiency (ŋd)

Amount of heat required to evaporate the moisture inside the product is called as drying efficiency. Total heat in case of solar dryer is the availability of solar radiation on collector surface of the dryer. This drying efficiency was calculated by equation no. (ii)

$$n_d = w \times \Delta H_L / A_C \times I_d \qquad \text{(ii)}$$

Where, W= moisture evaporated (kg)

ΔH= Latent heat of vaporization of water, 2260 ($kJkg^{-1}$)
Id= Total hourly insolation upon collector, (Wm^{-2})
Ac= Area of collector (m^2)

Average drying efficiency for salted fish was 14% and unsalted fish was 11% where as pickup efficiency for salted and unsalted fish was found as 10 and 9% respectively as shown in Figure 8.

Sensory evaluation

Solar dried salted prawns were most liked for its colour and texture where as unsalted sample was most liked for its overall acceptability, while traditionally open sun dried sample was least liked for its colour and texture. The vale of F is calculated as 1.98 during the sensory evaluation.

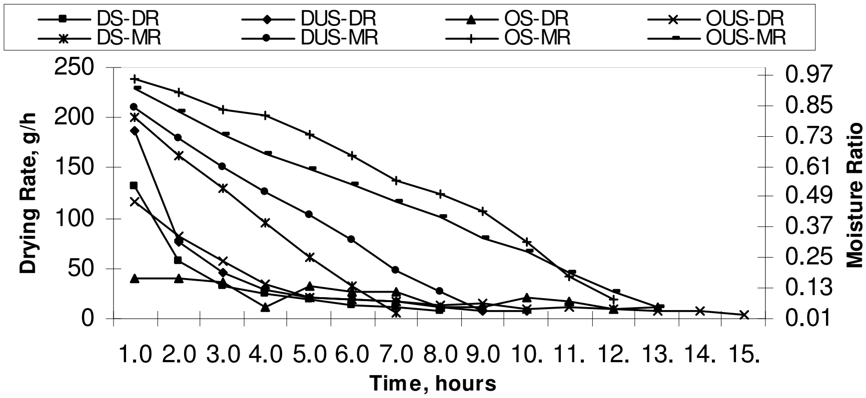

Figure 7. Variation of drying rate and moisture ratio with time.

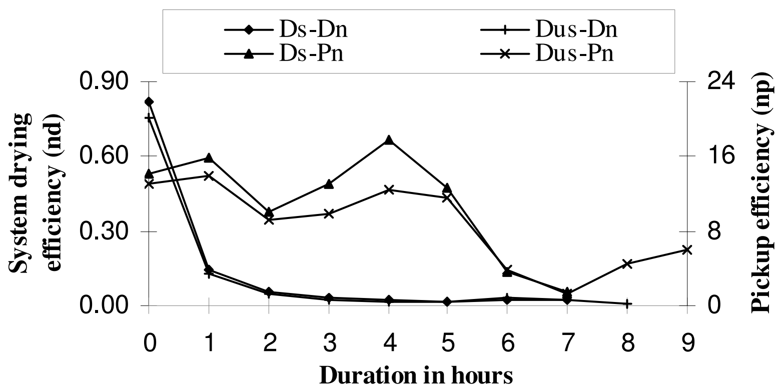

Figure 8. Variation of drying and pickup efficiency with time.

Table 2. Cost estimation of LCSD.

Item	Specification	Quantity	Rate (Rs)	Total (Rs)
Low grade ms pipe	40 mm dia.	8 m	50/m	400
Low grade heavy ms pipe	60 mm dia	1.5	100/m	150
Low grade bar	4 mm	10 kg	40/kg	400
Plastic	UV stabilized 200 micron	4 m^2	50/m^2	200
Velcro tape	2”	2 m	25/m	100
Wood strips	1”	30 m	3/m	100
Mosquito net	-	2 m^2	150/m	300
Miscellaneous	-	-	-	50
Total				Rs.1700

Economic comparing with conventional drying backup unit

The total cost of LCSD worked out to be Rs 1700 (Table 2). Approximately 19 kWh of electricity was required for obtaining daily output if LCSD unit was not used. If electricity unit charge was taken as Rs. 3.00; the cost of unit equivalent of electrical backup would be Rs. 57.00 for per batch.

Hence per day saving of LCSD would be Rs.57.00. Based on this calculation pay back period analysis of LCSD plant was calculated. It was observed that for

Table 3. Payback period of LCSD comparing with mechanical dryer.

Items	Comparison with Mechanical dryer electricity consumption (Rs.)
Initial Cost (Rs)	1700
Interest at 8% (Rs)	136
Savage value (10%)	170
Depreciation	153
Maintenance cost (3% of initial cost Rs.)	51
Saving per day (Rs)	57
Saving per year (Rs) for 200 days	11400
Pay back period (Yrs)	0.19

LCSD the costs could be recovered within the period of 0.19 year respectively (Table 3).

Conclusion

1.) Solar dryer is suitable for domestic drying of prawns' fish up to10 kg capacity.
2.) Salted fish dried inside the solar dryer were found better compare to unsalted for its colour and texture.
3.) Cost invested (payback period) on solar dryer Rs. 1700/- could be recovered within one month.

NOMENCLATURES

LCSD; Low cost solar dryer, **UV;** Ultra violet **M.C. (w. b.)**; Moisture content on wet basis, **M.C. (d. b.);** Moisture content on dry basis, **IMC;** Initial moisture content, **EMC;** equilibrium moisture content, **g;** gram, **η_c;** Collection efficiency, **h;** hour, **ŋd;** Drying Efficiency, **T1, T2, T3, T4 and T5;** Temperature obtained inside the dryer on tray position 1,2,3,4 and 5 respectively, **Ta;** Ambient temperature, **I;** Solar radiation, **Hi;** Inside humidity of dryer, **Ho;** Outside humidity of dryer, **DS;** Salted fish inside dryer, **DUS;** Unsalted fish inside dryer, **OS;** Salted fish outside the dryer(open condition), **OUS;** Unsalted fish outside the dryer (open condition), **DS-DR;** Drying rate for salted fish inside dryer, **DUS-DR;** Drying rate for unsalted fish inside dryer, **OS-DR;** Drying rate for salted fish outside the dryer(open condition), **OUS-DR;** Drying rate for unsalted fish outside the dryer (open condition), **DS-MR;** Moisture ratio for salted fish inside dryer, **DUS-MR;** Moisture ratio for unsalted fish inside dryer, **OS-MR;** Moisture ratio for salted fish outside the dryer(open condition), **OUS-MR;** Moisture ratio for unsalted fish outside the dryer (open condition), **DS-Dn;** Drying efficiency for salted fish inside dryer, **DUS-Dn;** Drying efficiency for unsalted fish inside dryer, **OS-Dn;** Drying efficiency for salted fish outside the dryer(open condition), **OUS-Dn;** Drying efficiency for unsalted fish outside the dryer (open condition), **'Ds-pn;** Pickup efficiency for salted fish, **Dus-pn';** Pickup efficiency for unsalted fish, **F;** Friedman's test.

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