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Development of Solar Dryer with Electrical Energy Backup for Hygienic Drying of Fish and Fish Products

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Abstract

Traditional sun drying methods under open sun for preserving low value fishery as well as agricultural products have several disadvantages such as contamination of food products by dust, dirt, birds, animals and insects and spoilage due to rain, wind and moisture. To overcome the disadvantage of open sun drying, a solar dryer with alternate energy backup of electricity was designed and developed for drying fishes and fish products hygienically in hot and humid climatic conditions. An experimental study on solar drying of small prawns was carried out and result was analyzed for validation of drying unit to be developed for hygienic drying of fish using solar energy. The experimental trials on solar drying were conducted using food grade stainless steel (SS 304) trays, drying chamber and solar heat collecting panels under controlled climatic conditions. The time required for reducing the moisture content of prawn to 8.7% was 8 h in the solar dryer. Colour and texture of the dried prawns prepared in closed drying chamber was found to be better than product prepared by other traditional drying methods. The collection efficiency of solar heat collecting panels was found to be approximately 82% and the distribution of hot air temperature inside the drying chamber was found to be uniform throughout the experiment. The average tray temperature inside the drying chamber at full load was 49ºC without any alternate energy backup. Water activity of dried prawns was found 0.6 and the drying rate was also calculated. Solar drying process was found to be hygienic and reliable with respect to product quality.

Keywords: Renewable energy, solar fish dryer, solar drying

Introduction

Presently, India stands on third position in global fish production as the production has been increased by 11 folds *viz.*, from 0.75 Mt in 1950-51 to 8.3 Mt in 2011-12 (Ayyappan, 2012). This sector provides livelihood and nutritional requirements to around 14.5 million people including traditional fishermen (Gopal & Edwin, 2013). The post-harvest loss in fisheries sector is significant in India. Fish is not only a nutrient dense but also highly perishable food material that cannot be stored as fresh without proper preservation. Most of the fishermen of the country are living below poverty line are unable to store their fish under refrigerated condition (Sengar et al., 2009). Several other preservation technologies like salting, canning, smoking, and hurdle technology can be employed for fish preservation but all are expensive in comparison to traditional sun drying (Kittu et al., 2010).

One of the important alternatives to refrigeration is 'solar drying' which is most attractive, cost effective and ecofriendly technique for food preservation to enhance the shelf life of fish (Fudholi et al., 2010). Dehydration is a well-known, efficient and effective method employed for the preservation of several food commodities like agricultural, animal and marine products (Singh & Mohammed, 1988). In drying operation, simultaneous heat and mass transfer take place from the product *viz.*, heat is externally generated and transferred to food material by hot air through convection that causes the evaporation of water from the inner part and surface of material which is continuously taken away by hot air. Generally, in solar heating system, storage of

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thermal energy inside the solar drier is enhanced during the day time and then this excess heat is continuously directed inside the drier to dry the stored product.

In developing countries like India, traditional sun drying *viz.*, drying under open sun is employed for the preservation of low value products and agricultural crops as one of the most inexpensive and extensively used technologies since early times. Major disadvantage of this method includes contamination of food products by dust, dirt, birds, animals and insects followed by their spoilage due to rain, wind and moisture which mainly governed by variable weather conditions. Moreover, this process is labour intensive, unhygienic, unreliable, time consuming that favour bacterial proliferation, non-uniform and requires a large area for spreading the products. Some of the problems associated with open-air drying can be solved through the use of solar drying (Sundari et al., 2013). Moreover, due to continuous increase in the cost of fossil fuels and uncertainty regarding future cost and availability, use of solar energy in fish processing will probably increase and become more economically feasible in the near future (Perasiriyan et al., 2013).

Closed chamber drying is having lot of advantages like saving in space and weight, decrease in transport bulk and cost, protection against contamination and microbial spoilage and retention of desirable quality attributes of fish. In this study, the drying process has been carried out to overcome the potential problems associated with traditional sun drying through the integration of an electrical energy source to the dryer as a separate component. The presence of an alternative energy source enables the continuous process of drying even in night hours.

Materials and Methods

Solar dryer with electrical energy backup was designed and fabricated, consisting two main parts *viz.*, solar collector and drying chamber made up of food grade stainless steel (SS304), connected by PVC ducting with minimum bends. Drying chamber can accommodate ten perforated/wire mesh trays (900×600 mm) with spacing of 70 mm for smooth flow and uniform distribution of hot air from solar heat collecting panels. The maximum capacity of drying chamber depends on spreading and also the size of fish which is being used for drying. Drying chamber was insulated with PUF insulation to minimize the heat loss to the environment. Drying chamber was divided into top and bottom compartments with five SS wire mesh trays placed in each compartment. Hot air from the solar heat collecting panels is drawn by the blower at middle portion of the drying chamber from the back side (Fig. 1). A divider is placed at the door side of drying chamber for bifurcation of hot air stream for uniform distribution inside the top and bottom compartments. The sets of trays in each compartment were placed in inclined manner (~ 63^o) for getting uniform distribution of hot air on each tray. Two rectangular exhaust openings (200 x 45 mm) with dampers were placed on bottom of each compartment at the back side of drying chamber as the tendency of moist air is to remain at the bottom of the chamber (Fig. 1). Alternate energy option of electricity (2.25 KW) was provided as a backup for heating the drying chamber during rainy season when there is insufficient sunshine.

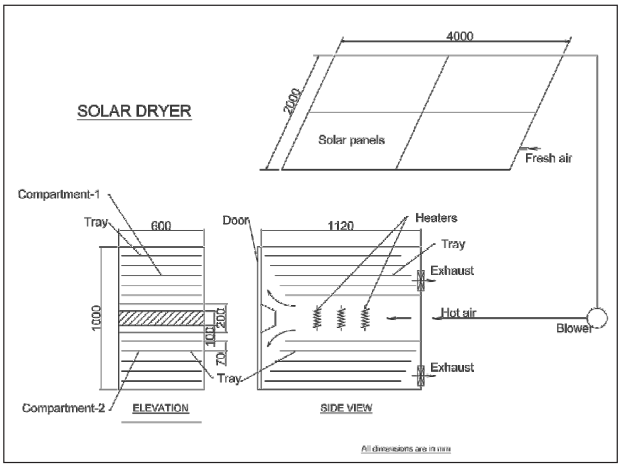

Fig. 1. Design diagram of Solar dryer with electrical backup (All dimensions in mm)

The four heat collecting panels were made of corrugated Aluminum sheets (1.5 mm thick) painted black and covered with toughened glass sheet of 5 mm thickness with total heating surface area of 8 m^2. Heat collecting panels were installed in an open space and facing towards south direction with inclination of about 25^{o}C for harnessing maximum amount of solar heat. Centrifugal blower (0.5 hp) was used to draw the hot air from the solar panel connected in the suction line of drying chamber. The ambient air enters inside the solar heat collecting panels naturally in such a way that it covers the maximum area of panels for getting heated sufficiently before entering into drying chamber. Dimensional details of the dryer are shown in table 1.

Fresh prawns (*Metapenaeus dobsoni*) collected from local market was washed in potable water and hot blanched in 2% brine for 30 s at 85ºC to get good colour and texture for the final product. One kg of sample on each tray (0.54 m^2) was spread and temperature sensors placed on the selected trays without touching the metallic tray. A Renewable energy monitoring system (EMCON-India) was used to measure the temperature, relative humidity, solar radiation and dry bulb temperature during the experiment. Drying parameters like moisture content, drying rate and collection efficiency of panels were also measured (Sengar et al., 2009).

Drying parameters were measured for 7 h, from 10 am. Air velocity inside the drying chamber and ducting was measured theoretically as well as experimentally during the trial using anemometer (Georg Rosenmuller, 806 Dresden). Water activity of the sample was measured by analogue water activity meter (DUROTHERM, Germany) before and at the end of drying. Temperature sensors were placed at second, sixth and eighth tray from top, middle and bottom of the drying chamber. The loss in water content was calculated on hourly basis by measuring the weight of the sample of each tray using electronic weighing balance (ELECON, India). Moisture content was measured using infrared moisture meter (Sartorius, Germany).

Collection efficiency** of heat collecting panels was measured theoretically and is given as

$$s_c = V\rho c_p \ \Delta T/A_c I_d$$

Where

V : Volumetric flow rate of air ($m^3 s^{-1}$)

ρ : Density of air ($kg\ m^{-3}$)

Ac : Collector area (m^2)

Cp : Air specific heat ($J\ kg^{-1}\ K^{-1}$)

I_d : Solar Insolation ($W\ m^{-2}$)

% Moisture Content** was calculated as $(w_1 - w_2/w_1)_{x\,100}$

Where

w_1 : Weight of sample before drying (kg)

w_2 : Weight of sample after drying (kg)

Drying rate** was calculated in terms of kg h^{-1} of bone dried weight, as was calculated as

Drying rate = $\Delta W/\Delta T$

ΔW : Change in weight (kg)

ΔT : Time interval (h)

** Sengar et al. (2009)

Results and Discussion

The average dry bulb temperature (DBT) and average atmospheric relative humidity (RH) were found to be 36ºC (Fig. 4) and 47% (Fig. 2) respectively. According to Rahman (2007), for effective drying, atmospheric RH should be less (<50%). The average solar radiation was found to be 704 Wm^{-2} (Fig. 4) and panel outlet temperature was 66.2ºC. Ambient RH varied with solar radiation and time (Fig. 2 & 3) and drying process inside the drying chamber would be affected by the climatic conditions. If the atmospheric air entering inside the panels is dry (low RH), the effectiveness of heat collecting panels would be more. Humidity inside

Table 1. Technical details of solar dryer with electrical backup

Name of component	Material	Size/Specification
Drying chamber	SS 304 PUF Insulated	1120 x 1000 x 600 mm
Drying trays	SS Wire-mesh 304	900 x 600 mm (10 nos)
Heat collecting panels	Aluminium sheet painted black	2000 x 1000 mm (4 nos)
Blower (centrifugal)		0.5 hp
Alternate energy backup	Electrical	750 W x 3 nos.
Ducting	PVC	Ø110 mm

the drying chamber can be controlled through opening and closing of exhausts.

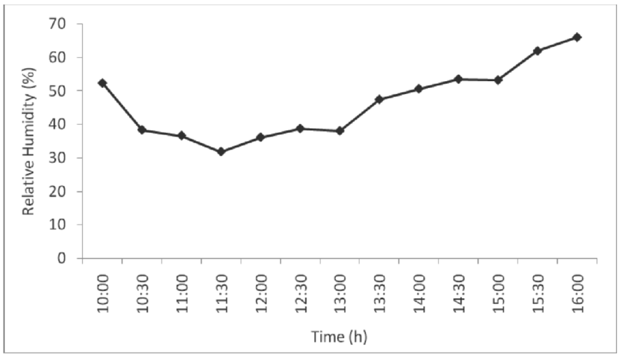

Fig. 2. Change in relative humidity with time

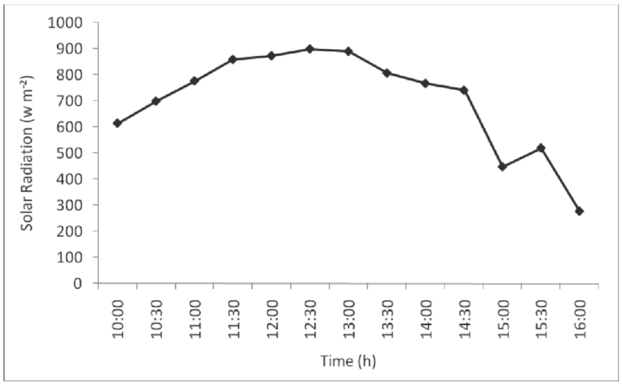

Fig. 3. Change in solar radiation with time

During present study the average efficiency of heat collecting panels was found to be 82%. The flow rate of hot air inside the drying chamber was found to be more than 90 m min^{-1} which is ideally suited for achieving standard drying. The temperature range required for effective drying is 45-55°C inside the drying chamber. It was observed that average tray temperature inside the drying chamber was 49.5°C (Fig. 4). The average temperature for top and bottom tray was about 51°C, and for middle portion it was 47°C which is suited to achieve the effective drying condition. Higher temperature (>60°C) inside the chamber is not suitable for drying as it may result in over drying or cooking which is not desired (Menon & Majumdar, 2007).

Drying rate was calculated on hourly basis during the drying process (Fig. 5). In the first hour of drying, rate of drying was high and it increased to 1.376 kg h^{-1} and subsequently it was reduced to 0.83, 0.46 and to 0.40 kg h^{-1}at the end of sixth hour. Average drying rate at the end of drying was found to be 0.82 kg h^{-1}. The change in the drying rate was due to the high moisture content of sample at the beginning and it continuously decreased with time. The variation in drying rate during the process depends on temperature and humidity condition inside the drying chamber. Also ambient condition such as solar radiation and temperature of incoming air varies with time and that would affect the drying rate throughout the drying process. Cumulative moisture loss was also observed during the experiment (Fig. 6) and found increasing by 0.98 kg to 4.925 kg at the end of 6th hour as continuous loss of moisture from the tray material throughout the drying process.

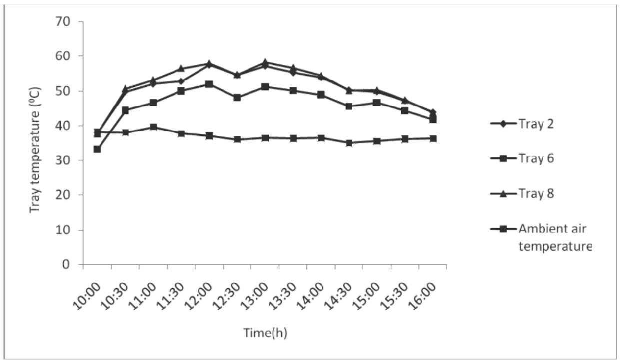

Fig. 4. Distribution of temperature with time

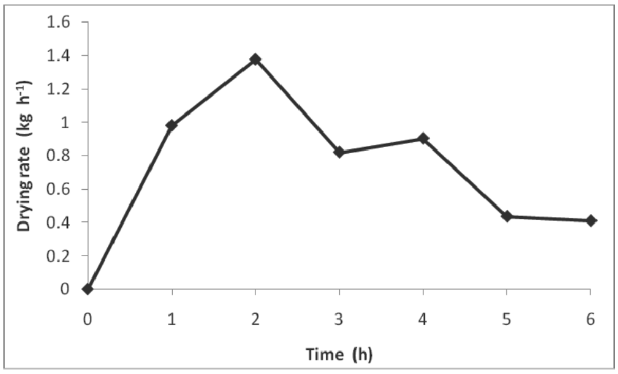

Fig. 5. Change in drying rate with time

Moisture content of the dried prawns at the end of drying process was found to be 8.7% and water activity at the end of drying was found to be 0.6. Moisture content of dried prawn was found to be far below the maximum limit of 20% stipulated for dried prawn in BIS standard (IS 14950:2001). Colour and texture of the dried sample were found good at the end of drying process.

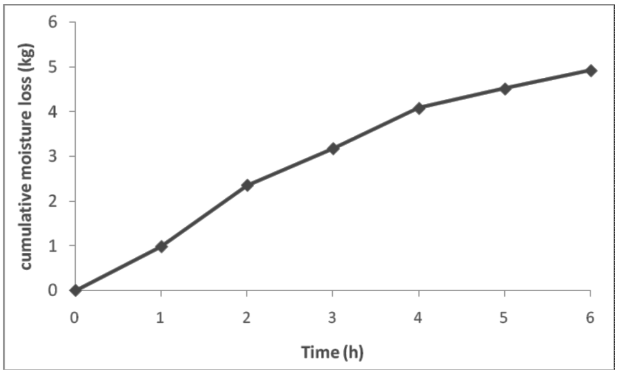

Fig. 6. Cumulative moisture loss with time

The solar dryer with electrical back up is ideal equipment for the hygienic preparation of dry fish products. The process is hygienic, requires less time and ensures quality of the end product. Water activity and moisture content were found to be within specified limits so that storage and transportation of the dried sample will be easy. The equipment can have versatile drying applications in agriculture sector. Power consumption will be minimal since the main energy source is solar energy. The electrical back up ensures continuous operation which is important for maintaining the quality of the dried product. The unit requires only limited space for installation. The total cost of the drying unit is around Rs.1 20 000/-. Operation of the dryer is easy and a single unskilled person can operate the dryer with minimum training. This equipment can be a viable option for commercial drying units in the coastal areas.

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