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***Research Article***

# OPTIMIZATION OF DRYING PROCESS FOR VEGETABLES AND FISH BY SOLAR TUNNEL DRYER

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## ABSTRACT
An experimental study was conducted to study the thin layer drying characteristics of vegetables and fish in a natural convection small scale solar tunnel dryer. Open sun drying trials were performed for comparison at the same time. The prototype model solar tunnel drier fabricated was 1.2 m long and 0.6 m wide. This system can be used for drying various agricultural products. Also, it is simple in construction and can be constructed at a low cost with locally available materials. Moisture content of vegetables was reduced in about 101 h in open sun drying, whereas the solar tunnel dryer took only about 86 h. Depending on weather conditions, the solar tunnel dryer was found to be more efficient than the open sun drying and resulted in saving to the extent of about 17.4% of drying time. Samples dried in the solar tunnel dryer were completely protected from insects, rain and dusts and the dried samples were of high quality in terms of colour and hygienic. The present new type tunnel solar dryer designed manufactured consisted of an air collector, drying chamber and an air circulation system. During the drying period, drying air temperature, relative humidity, solar radiation, and lose of moisture were measured continuously in different parts of the dryer.

***Key Words:*** *Vegetables, Solar Tunnel Drying, Open Sun Drying, Mathematical Model, Moisture Content, Effective Diffusivity*

## INTRODUCTION
Drying process is the most common form of food preservation and extends the food shelf life. It is a simultaneous heat and mass transfer operation in which moisture is removed from food material and carried away by hot air (Boiln and Salunkhe, 1982). A solar heating system is used to increase the thermal energy storage inside the solar drier during the day or to transfer excess heat from inside the drier to the heat storage area. Dehydration is a common technique for preservation of agricultural and other products, including fruits and vegetables Narinesingh and Mohammed (1988). In developing countries, the traditional method of dehydration is by open air, which often results in food contamination and nutritional deterioration. Some of the problems associated with open-air drying can be solved through the use of solar drying (Sundari *et al*., 2013).
Due to the current trends towards higher cost of fossil fuels and uncertainty regarding future cost and availability, use of solar energy in food processing will probably increase and become more economically feasible in the near future. Solar dryers have advantages over sun drying when correctly designed. They give faster drying rates by heating the air to 10-30$^{o}$C above ambient, which causes the air to move faster through the dryer, reduces its humidity. The faster drying reduces the risk of spoilage, improves quality of the product and gives a higher output. It requires less drying area. However care is needed when drying fruits that too rapid drying will prevent complete drying and would result in hardening and subsequent mould growth. Solar dryers also protect foods from dust, insects, birds and animals (Rossello *et al*., 1996; Fellows, 1997). They can be constructed from locally available materials at a relatively low capital cost and there are no fuel costs. Thus, they can be useful in areas where fuel or electricity is expensive, land for sun drying is in short supply or expensive, sunshine is plentiful but the air humidity is high. Moreover, they may be useful as a means of heating air for artificial dryers to reduce fuel costs. Solar food drying can be used in most areas but how quickly the food dries is affected by many variables, especially the

amount of sunlight and relative humidity. Typical drying times in solar dryers range from 1 to 3 days depending on sun, air movement, humidity and the type of food to be dried.

In open sun drying (OSD), rate of drying depends on intensity of solar radiation, ambient temperature wind velocity relative humidity (RH), initial moisture content, type of product, product asborptivity and mass of product per unit area exposed area. OSD has disadvantages resulting in product contamination, speed of drying and reduce nutrients in the end products including quality reduction in vegetables and fruits due to over or under drying, intermittent sunshine, wetting by rain etc. Hence this research with fabricated solar tunnel dryer presents the drying characteristics and quality of product produced in a natural circulation solar tunnel drier for high quality product.

The principle that lies behind the design of solar dryers is as follows: in drying relative and absolute humidity are of great importance. Air can take up moisture, but only up to a limit. This limit is the absolute maximum humidity, and it is temperature dependent. When air passes over a moist food it will take up moisture until it is virtually fully saturated, that is until absolute humidity has been reached. But, the capacity of the air for taking up this moisture is dependent on its temperature, higher the temperature higher the absolute humidity and larger the uptake of moisture. If air is warmed, the amount of moisture in it remains the same, but the relative humidity falls; enable air to take up more moisture from its surrounding (Szulmayer, 1971; Schirmer *et al.*, 1996). To produce a high-quality product economically, it must be dried fast, but without using excessive heat, which could cause product degradation. Drying time can be shortened by two main procedures: one is to raise the product temperature so that the moisture can be readily vaporized, while at the same time the humid air is constantly being removed. The second is to treat the product to be dried so that the moisture barriers, such as dense hydrophobic skin layers or long water migration paths, will be minimized.

## MATERIALS AND METHODS

In this experimental study, solar tunnel dryer with 0.75 $m^2$ base area and 0.6 m height was used for small scale for drying of vegetables and fish. The dryer was oriented in an east-west direction to make the incident solar radiation more efficient on the solar tunnel dryer. A corrugated galvanized iron sheet pointed black was used as an absorber plate for absorbing the solar radiation. It was oriented to the south under the collector angle of $20^0$C for maximum solar energy. UV (200µ thickness) stabilized polyethylene film materials was used as transparent material for the air collector to prevent the heat loss.

### *Methodology*

Agro products are highly hygroscopic and drying is a method of an approved method of improving their shelf life. The drying of food stuffs like fish and vegetables for dehydration in open air is not only labor consuming and but involves expenditure. The agro products contain more than 37% (w.b) moisture initially which has to be brought down to 11% (w.b) by drying. This is a critical process and it depends on monsoonic variations. Hence, it is proposed to integrate small poly cover in tunnel shaped structure designed as *Tunnel Shaped Semi Cylindrical* prototype model for drying agro-industrial product.

### *Equipment Design*

Tunnel shaped Semi cylindrical prototype model solar drier in the size of 3'x 2 was fabricated for drying of fruits and vegetables. It is a metallic frame structure of tunnel shape dryer covered by UV stabilized semi transparent polythene sheet of 200 micron thickness. No post is used inside the green house, allowing a better use of inside space. A slope of 10-15 degree is provided along the length of the tunnel. Chimneys on the top of the tunnel are provided to remove the moist air. Inside the drier the vessel was coated with black paint which keeps the samples to get exposed for higher drier performance. The drier is provided with black sheet bottom cover.

### *Salient features and its function*

- Maximum mean temperature obtained inside the dryer is 57° C ±0.19 while the ambient temperature was 33.5 °C±0.28.

- The drying time for solar tunnel dryer is less with 20% time saving when compared to open sun method
- This tunnel dryer can also be useful for drying of vegetables and fruits
- Simple in fabrication and installation.

Calibrated thermometers and RH meter (2 numbers) were fixed at different location inside and outside the drier to measure air temperature and humidity. Ambient humidity was calculated based on measured values of wet and dry bulb temperature.

Experiment was carried out under meteorological conditions of Chennai at college of food and dairy technology, Koduvalli, Chennai-52 in an open area during the Month of January 2013. On the basis of measurement, potential sunshine duration at this location was measured as 8 hr per day (9.00-5.00pm). Matured and good quality vegetables *(Onion, Tomatoes, Turnip, Carrot, Fish, Mint, Potato and Chilli)* were cut into similar small pieces and then pre-treated as follows.

***Pretreatment procedure for Fruits & Vegetables***

***Tomatoes***

Due to the increasing demand for dried tomatoes from the industry, especially from the soup manufacturers, interest is focused on producing high quality dried tomatoes. Therefore, it is important to establish a drying method, which yields products with higher sensory and sanitary quality in a shorter drying time compared to the conventional sun-drying method. Both 2% $Na_2S_20_5$ and 2% citric acid pretreatments can be used to protect the bright, red colour of tomatoes. However, citric acid did not prevent the growth of moulds and yeasts effectively. Therefore, dipping into sodium metabisulfite solution for 3 minute pretreatment was done following drying of tomatoes at 55°C in solar tunnel dryer without darkening. At this temperature the drying takes 4-5 days to reach a final moisture content of 11 %

***Onion***

A large part of the dehydrated onion production is used as seasoning in production of catsup, chilli sauce and meat casseroles, as well as cold cuts, sausages, potato chips, crackers and other snack items. Food service outlets also use dehydrated onions because of its convenience in storage, preparation and use. Before drying, onions are peeled and sliced into desired shapes. Onions can be dried at 45-50°C for 2-3 days to a final moisture content of 15 % in tunnel solar dryers. Sodium metabisulfite dipping can be used to preserve colour. Drying temperatures of onions should not exceed 50°C in order to prevent browning of the product. The yield in onion drying was 8%

***Carrot***

Before loading into the dryer, carrots were peeled, washed, cut into small cubes and treated with 2% sodium metabisulfite solution for 1s and 10s. Carrots can be dried at 50-55°C for 1-1.5 days to a final moisture content of 7.5 %. Naturally dried carrots lose their bright orange colour. The sodium metabisulfite treated ones preserve their colour to the largest extent.

***Potato***

Potato is one of the most popular vegetables consumed in tropical and subtropical countries. Before loading into solar dryer, potato is washed and its head is removed. The following treatments can be applied to potato prior to solar drying steam blanching dipping in the water containing 1 tea spoon of sodium bisulfate per cup of water for 4-6 min followed by rinsed with water as a pretreatment and drying of Potato at 50-55°C in the solar dryer was done.

***Turnip***

Before loading into the dryer, turnips were peeled, washed, cut into small cubes and steam blanched for 5 to 8 minutes. Turnips can be dried at 50-55°C for 1-1.5 days to a final moisture content of 7.5 %.

***Mint***

Before loading into the dryer, mints were cleaned, washed, cut and steam blanched for 2 minutes. It can be dried at 40-45°C to the final moisture content.

***Fish***

Fish samples were dipped in 1 liter of boiling water (100 $^0$C) for about 5 minutes and arranged on trays for about 30 minutes to remove all surface water from the fish before arranging them on the drying trays in the dryer.

Calibrated thermometers (2 numbers) were fixed at inside and outside the drier to measure air temperature and humidity. Initial weight was calculated for all vegetables (six samples each). They were arranged in the plate which is coated with black paint for increasing the absorption of solar radiation. They were kept inside the solar drying chamber. Another set (6 sample of each item) were kept outside the drier. Then temperature and humidity was measured every 1hr interval till the end of the drying process both inside the drier and outside the drier.

For the determination of moisture content, samples were weighed every 1hr interval in an electronic weighing balance compared with initial weight and final weight of the particular sample.

## RESULTS AND DISCUSSION

***Results***

The studies on optimization of drying process for fish and vegetables were carried out in two drying pattern namely solar tunnel drier and open sun drying. Solar tunnel drier was designed as prototype model fabricated with 1.2 m length and 0.6m wide. This system has superior drying efficiency in terms of increased rate of drying and also the quality product which helps improved shelf life.

The environmental conditions of the experiment were tabulated.

**Table 1: Temperature and Relative humidity at different time period**

| S.No | Temperature ($^0$C) | | Relative humidity (RH %) | |
|---|---|---|---|---|
| | Out side | Inside | Outside | Inside |
| 1 | 33.3 | 39.9 | 51 | 39 |
| 2 | 34.3 | 43.4 | 42 | 34 |
| 3 | 32.2 | 38.1 | 54 | 40 |
| 4 | 31.1 | 35.5 | 42 | 32 |
| 5 | 30.0 | 35.0 | 34 | 25 |
| 6 | 29.0 | 33.0 | 41 | 32 |

Food stuffs like vegetables and fish were taken for the experiment and the results were recorded. The replicates were analysed statistically.

**Table 2: Weight in grams of agro products under drying process (Average of six samples)**

| S.No | Product | Solar drying | | | | Sun drying | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Initial | 1 hour | 2 hour | 4 hour | Initial | 1 hour | 2 hour | 4 hour |
| 1 | Carrot | 50 | 24 | 13.5 | 9 | 50 | 34.5 | 28 | 20 |
| 2 | Potato | 65 | 36 | 22.5 | 16 | 65 | 46.5 | 38.5 | 23.5 |
| 3 | Turnip | 50 | 25 | 13.5 | 6.5 | 50 | 32.5 | 25.5 | 17 |
| 4 | Mint | 15 | 3 | 1.5 | 1.0 | 15 | 4.0 | 1.0 | 1.0 |
| 5 | Tomato | 50 | 21 | 10 | 4.5 | 50 | 34 | 26.5 | 13 |
| 6 | Onion | 70 | 26.5 | 18 | 10.5 | 70 | 35 | 22.5 | 15 |
| 7 | Fish | 38 | 26.5 | 17.5 | 13 | 38 | 27.5 | 23.5 | 18 |

In sun drying method, the average removal of moisture % for vegetables including the fish was found to be 39.6 % at the end of first hour, 14.7 % for the second hour and 15.45% for the period of drying from second to 4$^{th}$ hour. Whereas in solar drying the average removal of moisture % for vegetables including the fish was found to be 53.85 % at the end of first hour, 18.92 % for the second hour and 10% for the period of drying from second to 4th hour. Hence the comparison shows that 36% increased rate of drying during first hour followed by 28% during the second hour in the solar drying.

**Table 3: Percentage of moisture removed under solar and sun drying**

| S.No | Product | Solar drying | | | Sun drying | | |
|---|---|---|---|---|---|---|---|
| | | 1st hour | 2nd hour | 3rd&4thhour | 1st hour | 2nd hour | 3rd&4thhour |
| 1 | Carrot | 52 | 21 | 9 | 31 | 13 | 16 |
| 2 | Potato | 44.6 | 20.8 | 10 | 28 | 12.3 | 23 |
| 3 | Turnip | 50 | 23 | 14 | 35 | 14 | 17 |
| 4 | Mint | 80 | 10 | 1 | 73 | 20 | 0 |
| 5 | Tomato | 58 | 22 | 13 | 32 | 15 | 27 |
| 6 | Onion | 62 | 12.1 | 10.7 | 50 | 18 | 10.7 |
| 7 | Fish | 30 | 23.6 | 12 | 28 | 10.5 | 14.5 |

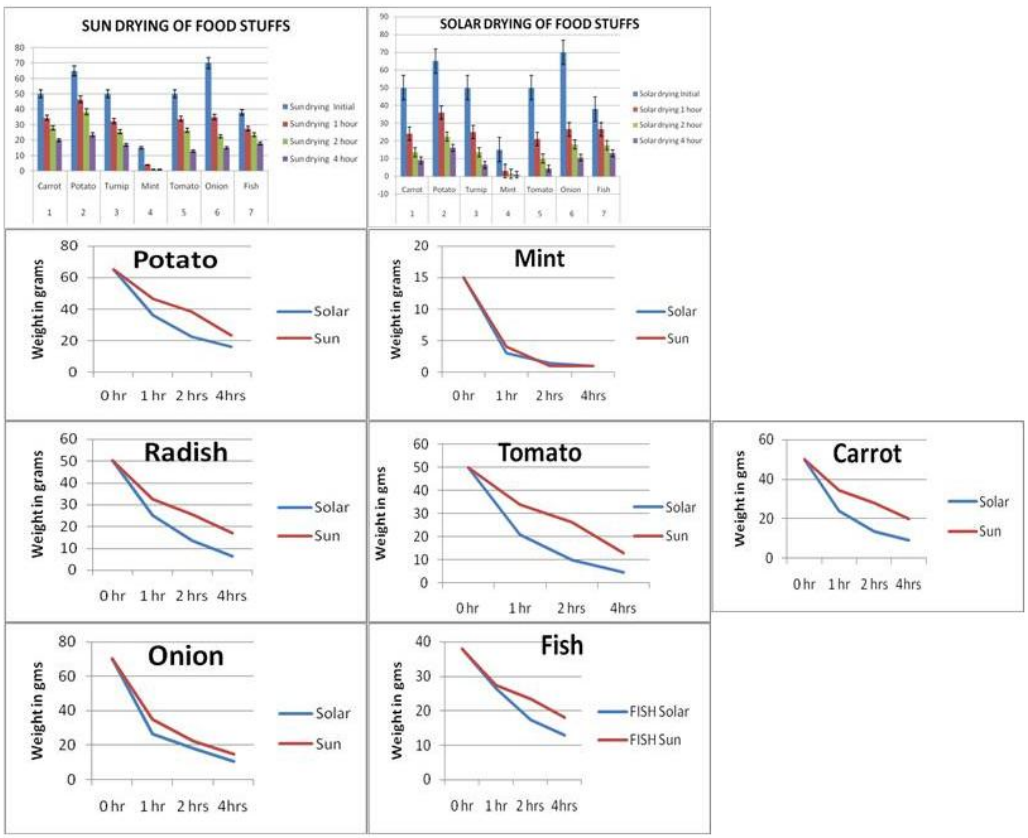


**Figure 1: Drying efficiency of solar and sun drying**

***Discussion***

Due to the current trends towards higher cost of fossil fuels and uncertainty regarding future cost and availability, use of solar energy in food processing will probably increase and become more economically feasible in the near future. Solar dryers have certain advantages over sun drying when correctly designed. They give faster drying rates by heating the air to 10-30°C above ambient, which causes the air to move faster through the dryer, reduces its humidity. The faster drying reduces the risk of spoilage, improves quality of the product and gives a higher output. It requires less drying area (Sundari *et al.*, 2013). In this study the maximum solar intensity recorded was 34.3$^0$C maximum temperature recorded inside the chamber was 43.4$^0$C during peak sunshine hours and temperature reduced during off sunshine hours and nights. Range of RH% of air inside solar tunnel drier was 25 to 40% as compared to average RH of ambient air 41 to 54% indicating that air inside solar tunnel drier had high drying potential as compared to ambient air. Air velocity varies (Increases) during drying period under natural convection.

Demir and Sacilik (2010) recorded that the use of solar tunnel drier let to considerable reduction in drying time in comparison to open sun drying apart from the protection of tomatoes from insects and dust. The present report coincide well with the above findings in recording the faster drying rate in solar tunnel drier and recommends for better quality of food stuffs as reported earlier (Oparaku, 2012; Ayyappan and Mayilsamy, 2010; Enein, 2000).

The solar drying was found to be superior in maintaining the shelf life of the agricultural produce and recorded to retain higher lipid content than open sun drying (Oparaku, 2012). There was a significant increase in lipid contents in the solar drying which suggests and supports the results of the present findings that the nutritional qualities of perishable food stuffs like fish could well be maintained and retained as reported by the authors.

The sensory evaluation reports (Enein, 2000) supported solar tunnel dryer rather than open sun dryer in retaining the quality of the produce tested and gained good acceptance for its colour, aroma and texture.

Average moisture content of produce was reduced from 52% to 8% after 60 hr under full load in solar tunnel drier. Moisture removal rate from fruits and vegetables was high during initial stage of drying. Reduction in moisture content of the particular product is higher which is placed in the center of the chamber compared to the sides of it. Solar tunnel drier is to be found to produce high quality compared to open sun drying, possibly due to less humid drying environment provided by the solar tunnel drier in the absence of microbial activity. High quality product produced in solar tunnel drier fetches more market prices for all agricultural farmers.

### *Conclusion*

The optimization of drying process for fish and vegetables were carried out in two drying pattern namely solar tunnel drier and open sun drying. The solar drying was found to be superior in maintaining the shelf life of the agricultural produce tested in terms of relative rapid drying and maintaining shelf life. The comparison showed that 36% increased rate of drying during first hour followed by 28% during the second hour in the solar drying. Hence the adoption of solar drying would recommend for high quality product. Thus the products dryed in solar tunnel drier fetches more market prices for all agricultural farmers.

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