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Design and development of solar dryer for food preservation

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Abstract

Solar thermal energy is an alternative source of energy which can be used for drying vegetables, fishes, fruits or other kinds of material, such as wood. In Bangladesh, there exist significant post-harvest losses of agricultural products due to lack of the use of proper preservation system. Drying by using solar thermal energy can be an effective solution for this loss. As Bangladesh is situated in latitude 23°43'N and longitude 90°26'E, this is very much suitable to use solar thermal energy. To reduce the limitations of the natural sun drying e.g. exposure of the foodstuff to rain and dust; uncontrolled drying; exposure to direct sunlight; infestation by insects etc., two types of solar dryer (low cost solar dryer for small production and solar dryer for large production) were developed. The design was based on the geographical location of Dhaka, Bangladesh. The experiments were conducted to dry vegetables and fishes. The obtained results revealed that the temperatures inside the dryer were much higher than the ambient temperature. The rapid rate of drying proves its ability to dry food to keep in safe moisture level in a hygienic environment. Microbiological and nutritional values ensure a superior quality of the dried product also.

Keywords: Solar energy; Solar dryer; Insolation; Natural Circulation; Mixed-mode; Moisture

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Introduction

Bangladesh is an agricultural country. Every year it produces enormous crops, vegetables and fruits. During the peak harvest period there is often a significant over abundance of produce. It has been estimated that more than 40% of the food losses occur at post-harvest and processing levels in developing countries (Gustavsson *et al.,* 2011). Therefore, it is badly in need to preserve the produced harvests. Drying is the oldest and an excellent way to preserve foods for long time because the moisture content is so low that spoilage organisms cannot grow. Furthermore in some cases a crop may require drying so that it can be further processed and make a new product. But drying is an energy consuming industrial process. It requires approximately 2.4MJ to evaporate one liter of water (Gálvez *et al.,* 2010). The use of renewable energy in power sector is being given emphasized because of the limited source of energy and to reduce global warming. Therefore, drying process using renewable energy sources like solar energy may be one of the alternatives. Solar drying is widely used in many tropical and subtropical countries because of its simplicity and inexpensive technique. However, some of the disadvantages of open air solar drying can be mentioned as: exposure of the foodstuff to rain and dust; uncontrolled drying; exposure to direct sunlight which is undesirable for some foodstuffs; infestation by insects; attack by animals etc. In order to improve the drying method, solar dryers which have the potential of substantially reducing the above-mentioned disadvantages and also to accelerate the time for drying the products by controlling the final moisture can be used.

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Depending upon the mode of air circulation, solar dryers can be classified into two categories, such as natural circulation and forced circulation dryers (Phadke *et al.,* 2015). In natural circulation system, an outlet vent is provided at the top part for exit of the warm moist air through natural convection. It does not need any fan to blow the air, whereas, forced circulation solar dryer uses fan and forces air to pass through the dryer. As the forced convection system can control the air flow rate, it has higher drying capabilities compared to the natural convection system.

According to the type of dryings, solar drying technologies are broadly classified into three modes, like, direct solar drying, indirect solar drying and mixed mode solar drying (Phadke *et al.,* 2015). Direct dryer dries the products by direct heating of sun which enters through a transparent cover (Duffie and Beckman, 1980). It may also use reflectors to increase the temperature. Indirect dryer consists of a separate chamber called the air heater or collector. The air is heated when it passes through the collector and enters in drying chamber (Simate, 2001). The hot air flow dries the product and removes the moisture by using outlet of dryer. A mixed mode dryer combines the both direct and indirect dryers. Here, product is dried simultaneously by direct radiation through the transparent cover and the convection of heat from the solar collector, which in turn accelerates the drying rate (Simate, 2001). Fig. 1 shows the classification of solar dryers and drying modes (Leon *et al.,* 2002).

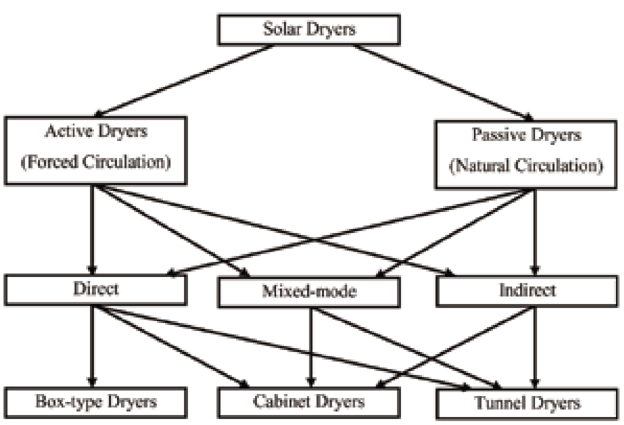

Fig. 1. Classification of solar dryers

Solar dryers have been reported in both theoretical and experimental studies. Chaudhari and Salve (2014) presented a comprehensive review of cabinet type, green house type, chamber type and tunnel type solar dryers with design parameters and performance. They showed that for large quantity of product drying, it is better to use the green house type solar dryers. Bolaji (2011) showed that mixed mode and indirect mode solar dryers are more effective in utilizing the captured energy than direct mode dryer, and mixed mode has a slight edge in superiority over indirect mode system. In particular the solar dryer technology is effective for agricultural products preservation (Babagana *et al.,* 2012). Mohsin *et al.* (2011) has worked out on design and performance analysis of different types of solar dryers and their prospect in Bangladesh.

To identify the most appropriate and economic solar dryer design and the diffusion of such systems among the real users can be a great challenge (Sharma *et al.,* 1995). The aim of this work is to focus on designing and fabricating simple direct natural convection dryers suitable for Bangladesh and it can be an attempt to solve the above mentioned problem. A brief design description, details of the experiments, evaluation the product quality with respect to microbiological test and nutritional value and the conclusion drawn are the prominent features of this work.

Materials and methods

The basic theory of solar drying is utilizing incident solar radiation and converts it into thermal energy required for drying purposes. Basically, solar dryer contains different collectors which heat the air and heated air is then passed through the drying chamber to be dried. The latent heat of vaporization required to remove moisture from the product is provided by the hot air flowing through the dryer. The air flow through the dryer is an important factor in the drying process and is responsible for moisture transport by enhancing convective transfer of water vapor from the raw material to the dry surrounding air by outlet.

In this study, two types of solar dryer have been designed, developed and analysed in different months:

1. Low cost solar dryer for small production
2. Solar dryer for large production

Fig. 2 shows the schematic diagram of a solar dryer that has been developed for small scale production. Due to low cost and simple operation and maintenance, this appears to be the obvious option and popular choice for drying of agricultural products at home. The dimension of this dryer is 0.91m length×0.76m width×0.61m height with tilted transparent top and is constructed with available materials readily available in Bangladesh like wood and transparent plastic. Since agricultural products which are mostly available in winter and maximum solar insolation getting around in 40° at that time, so the angle of heat collection is calculated as latitude plus 15 degrees that is 38°. It provides air inlet and outlet holes at the lower and back side respectively. The outlet vents are at higher level. Sun ray passes through the transparent plastic cover and heats the air inside the dryer. This heated air dries the agriculture products and moves out through the outlet vents.

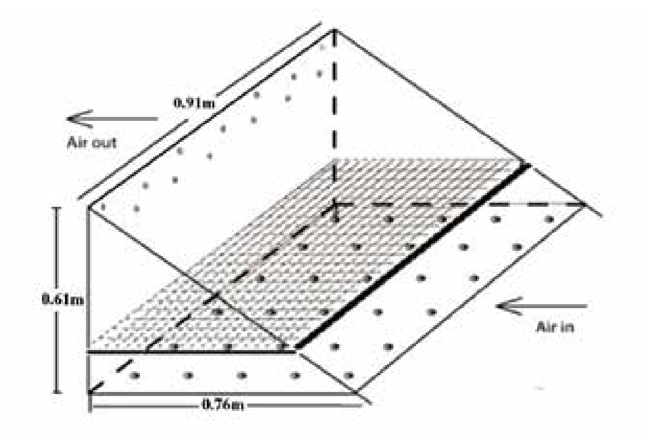

Fig. 2. Low cost solar dryer for small production

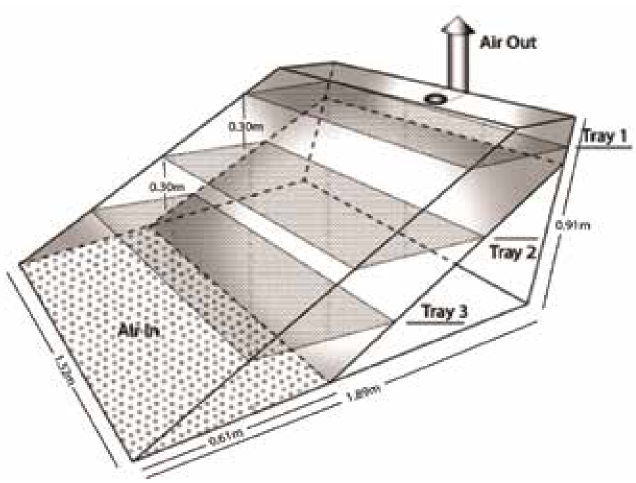

Fig. 3. Solar dryer for large production

A direct mode natural convection solar dryer has been designed to receive and utilize maximum solar energy in a chamber which is shown in Fig. 3. This solar dryer has been developed for quite large scale production. The dryer consists of three main parts: solar collector, drying trays and outlet chimney. The solar collector that acts as drying chamber has the dimension of 1.52m length×1.89m width ×0.91m tilted height. The drying chamber is tilted with transparent glass top so that the sunlight can pass through the glass and reach to all the drying trays. Inside the drying chamber there are three movable stainless steel mesh trays. The frame of each tray has been constructed by thai aluminum with dimensions of 1.52m length×0.55m width. Three tray holders made of angle of thai aluminum are set up in such a way to hold tray inside drying chamber. The lower holder is 0.15m above the absorber plate (made of blackened metal sheet) and the upper holder is 0.15m apart from transparent glass of the top. The distance between two adjacent tray holders is 0.30m. Transparent glass of 0.005m (i.e., 5mm) thickness is used on top and tilted parts of the dryer. The air from outside enters through the inlet air holes located at the base of absorber plate. It blows through the drying chamber and goes out from the chamber by using outlet vent shaped as chimney which is located on the upper side of the back edge. The dryer is set on four wheels to make it mobile. Fig. 4 shows the pictorial view of solar dryer that has been installed to accomplish the study.

Fig. 4. Pictorial view of Solar dryer for large production

The aim of our experiment was to remove moisture content from a given quantity of wet products to bring the moisture to a safe storage level in a specified time. The amount of moisture to be removed from the product in percentage can be calculated using the following equation:

Moisture remove (%) = (Initial weight - After drying weight) × 100/Initial weight

Average drying rate can be calculated by the following equation:

Average drying rate, $$m_{ave} = \frac{m}{t}$$

Where, m is the amount of moisture content removed and t is the daily sunshine hours.

Field level studies were conducted at IFRD, BCSIR to demonstrate the potentiality of the solar driers for production of high quality solar dried vegetables, fishes and medicinal plants. Before drying, vegetables were processed. Potato and carrots were sorted to remove defects, washed and then sliced with sharp slicers into approximately 0.003m (i.e., 3mm) thick slices. They were weighted and placed on drying trays. Also another tray of vegetables was kept in open air to compare the effectiveness of the dryer. Before placing into trays, vegetables were weighted and moisture contents were determined. Testing was performed from October to December in the year of 2015. Ambient air and drying chamber temperatures were measured with digital thermometers. Solar radiation was measured with solar tracking system of Kipp & Zonen with pyranometer (SMP3-V), phrgeometer (CGR-3), pyrheliometer (SHP1), sunshine duration sensor (CSD3) and automatic sun tracker (SOLYS32). The sliced vegetables were sampled out periodically and the moisture content was measured by moisture analyzer. Measurements were done at 15 minutes intervals.

Results and discussion

By analyzing several data we've found that, in the month of December when the solar insolation is low, the first type of solar dryer (for small production) needs 6 hours to dry 1 kg cabbage properly. After six hours, the remaining moisture of the cabbage (taken from the dryer) was 4% and that was 12% for open air. The result was almost same for other vegetables like potato and carrot. The average drying rate for the dryer was 0.428 kg/hr as against 0.300 kg/hr for open sun drying. The detailed experiment was done for second type of solar dryer (for large production).

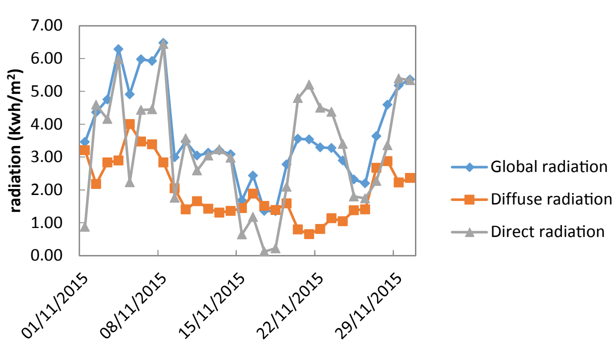

Fig. 5. Solar insolation data of November 2015

Fig. 5 shows the solar insolation data of the month of November, 2015 in Dhaka. The average global radiation was found to 4 KWh/m^2. All the experiments were done at the same place. Fig. 6 shows the solar insolation data on 18th October, 2015 which indicates that the active sun hour is 6h 35m; global, diffuse and direct irradiations are 4.38KWh/m^2, 1.64KWh/m^2 and 4.96 KWh/m^2 respectively. In that day, the temperatures of the different trays in solar dryer were measured with time in without load condition as shown in Fig. 7. The graph shows that, at 11:30AM, the temperature of the dryer falls down and then again increases with time. It is due to the decrease of solar irradiation at the same time which is shown clearly in Fig. 6. From the graph we can see that the average ambient temperature is almost between 34 to 35°C. But at the same time, the temperature inside the dryer is between 70 to 80°C. The graph also illustrates the temperature variation in different trays based on their positions. The upper tray has higher temperature than the adjacent lower tray. This is due to the nature of hot air flow that generally moves to the upper side.

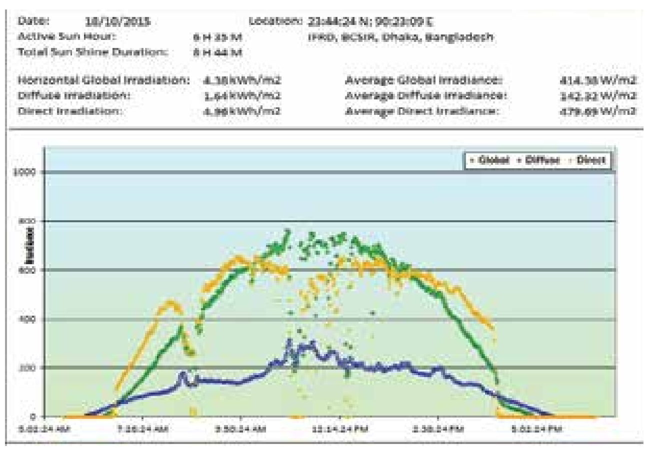

Fig. 6. Solar irradiance data of Dhaka on 18th October, 2015

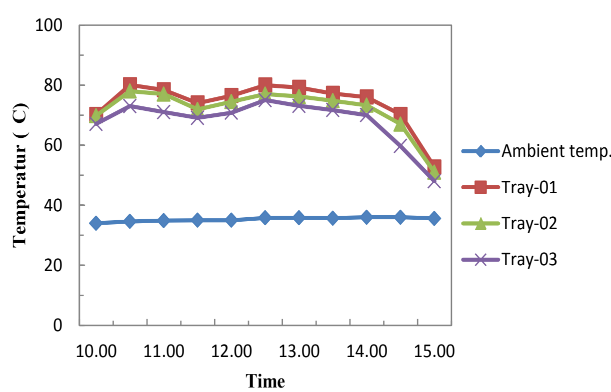

Fig. 7. Temperature vs. Time graph without load condition (18th October, 2015)

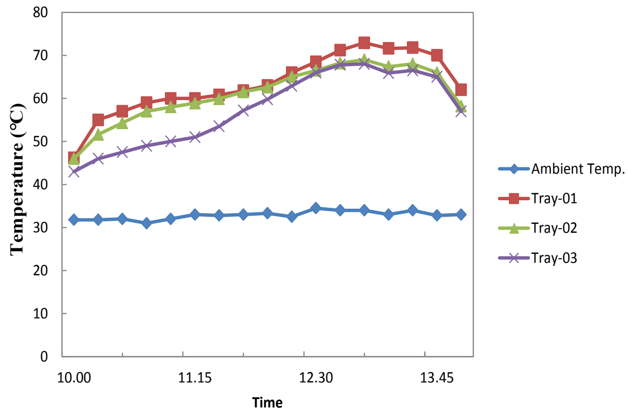

Fig. 8. Temperature vs. Time graph with load condition (23rd November, 2015)

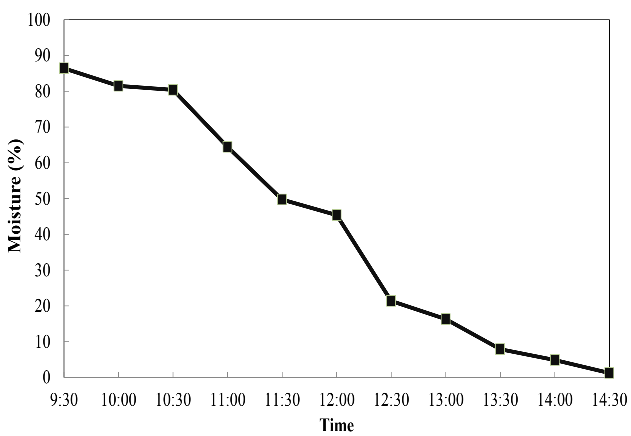

Fig. 9. Moisture content variation with time (29th November, 2015)

Fig. 9 shows the moisture content variation with time. Here, 500g carrot was tested with initial 86.41% moisture. After 5 hours, the moisture content reached to only 1.24%. The dried carrot was microbiologically tested (bacteria and fungi) and found safe for human consumption, since the total plate counts were within the acceptable limit of $<10^5$cfu/g recommended by International Commission on Microbiological Specification for Foods (ICMSF). The effect of nutritional values on dried vegetables (potato & carrot) has been measured which is shown in Table I. The protein content is almost similar to the standard result of G. Kibria *et al.* (1996). This dryer can dry 5 kg carrot or potato within a day.

Conclusion

Different tests have demonstrated that solar driers are appropriate for production of quality dried fruits, vegetables, medicinal plants and fishes. In all the cases the use of solar driers leads to considerable reduction of drying time in comparison to open sun drying. Also the drier produces the good quality hygienic dried products. However, the drying time increases with the increase of humidity in the air. It also depends on the incident solar insolation. Solar driers are simple in construction, low cost and can be constructed using locally available materials.

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This research work has been carried out at the Institute of Fuel Research and Development (IFRD) and the microbiological and nutritional tests have been performed at the Institute of Food Science and Technology (IFST), Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka, Bangladesh.

Table I. Effect of nutritional value on dried vegetables (potato & carrot)

Sample	Protein (%)	Fat (%)	Ash (%)	Fiber (%)	Carbohydrate (%)
Dry potato	9.36	0.12	3.24	4.92	83.75
Dry carrot	8.25	1.09	4.30	10.56	77.31

Fig. 8 shows the nature of temperature in the dryer with time in loading condition. Here, the temperature in dryer is little bit lower compared to without load condition due to the loading effect. The average drying rate for the dryer was 0.5 kg/hr.

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