ICMIEE18-222

Experimental Investigation on Three Different Natural Convection Cabinet Solar Dryer for Food Drying Applications

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ABSTRACT

The development and investigation of efficient solar drier, particularly meant for drying vegetables and fruit is described in this paper. Considering the importance of solar drying three different types of natural convection cabinet solar dryers are constructed and their performance are evaluated at natural conditions. To do so moisture removal rate, moisture ratio of various foods (Apple, Banana, pineapple, Guava) are evaluated from 10AM to 4PM for many days in different season. After analyzing the dehydration rate of three different chambers it is appeared that total dehydration of thin tube chimney type chamber is 44.5%, for attic space type chamber dehydration is 33.3% and for natural draft chamber it is 58.9% in 6 hours. So, it is clear from this analysis that the performance of natural draft chamber is best than other two chambers and performance of attic space type chamber is worst. This is due to the reflection loss in inclined glass of attic space type dryer compared to other chambers. Besides, the performance of chimney chamber is better than attic space type chamber. It is also seen that dehydration rate after 1pm is higher than before 1pm as solar irradiation was higher after 1 pm in best performance days. Besides, dehydration rate of Pineapple is the highest as water level and porosity is so much high and for guava is the lowest as water level and porosity is low. Dehydration rate of banana is higher than guava but lower than apple.

Keywords: Solar drying, Thin tube chimney type dryer, Attic space type Dryer, Natural convection solar dryer, Dehydration

1. Introduction

World's population is increasing in a faster rate and demand of food is increasing as well. With the developments of agricultural technology, production of food is expanding to meet the demand. Solar drying is one of the renewable forms of food storage that can reduce processing cost for storage. However, it has some problem of product discoloration in drying, might cause microbial infestation, and requires longer time for dehydration, loss of product in the process. Production of certain agricultural goods is higher in a particular season than demand but scarce in another season in Bangladesh. As a result, price falls in production season but rises higher in scarce time. Peasants cannot store their products due to lack of storage and high cost affiliated with it. So, food is wasted every year which might have been utilized to serve the countries growing population. Similar things happen in our fisheries sector. But solar drying in open environment which is naturally carried on can pollute the product, product loss due to wastage is common thing. Besides solar energy is not available at night and its intensity fluctuates with time. So, improvement in drying performance is necessary to reduce its drying time. For proper distribution of food around the globe their need a proper food production, supply and storage management for favor of mankind. Every year a huge amount of produced food is wasted due to proper storage of foods. This occurs for limited storage capacity, high charge of storage, lower price of produced food, transportation problem. So, farmers make waste of the food when it is loss for them. In developed countries they produce biofuel from the excess of produced food, but it is a controversial fact as it effects human and animal food supply. Most of the developing countries are facing difficulty in solving their food problems as their population are vastly increasing but food quality and quantity is deteriorating due to inferior processing capability and storage shortage. For proper circulation of food among the population, reduction of food losses during harvesting season is necessary [1]. During the production season of any food its quantity is abundant so it's more than demand and as a result price drop. So, farmers need to preserve food for a longer period to supply it later the market when price rises and to meet the demand. There are many methods available for preservation of food like canning, chemical treatment, dehydration, refrigeration, controlled atmospheres use of subatomic particles of which dehydration is the tolerable approach providing solar radiation as the major energy source [2]. Ziafooughi et al. [3] presented an indirect solar assisted intermittent infrared dryer to investigate the effective parameters in the drying system. But in this case high amount of electric energy is needed which might not be afforded for the rural people of Bangladesh. Dehydration is most suitable for foods which have high moisture content, prone to microbial infestation. Different foods have maximum temperature and heating rate limitation as drying is a slow energy consuming process otherwise its quality will be ruined [4-5]. Solar drying is a promising alternative for food drying in Bangladesh, because mechanical drying is largely used in industrial countries and is not applicable to little farms in developing countries due to high investment and operating costs. A mixed mode type

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solar dryer consisting of dryer and collector was studied by Hossain et al. [6]. The dryer is composed of drying chamber, drying tray, and vent and used for chilly drying. An energy analysis of solar drying of jackfruit in a solar tunnel dryer was presented by Chowdhury et al. [7]. Jackfruit was dried from an initial moisture content of about 76% (w.b.) to 11.88% moisture content (w.b.). Kaewkiew et al. [8] studied the performance of a large-scale greenhouse dryer to dry red chili in Thailand. They dried 500 kg of red chili using this dryer and reduced the moisture content from 74% to 9% in 3 days. Use of solar energy is a viable solution for dehydration. Drying foods using solar energy are carried by open sun drying and solar drying. Products are directly subjected to sun in open sun drying. This method is the cheapest and economical option for drying foods, but it is a labor intensive process, leads to contamination of the food, requires larger area, slower drying rate and sudden exposure to rain, may result in discoloration of the product, lead to microbial infestation and product loss due to contamination, animal or bird eating [9-10]. Various types of open sun drying are specified based on the location, procedure of processing or the way solar radiation is utilized. For these reasons solar drying is a feasible alternative which can provide clean, hygienic drying of food maintaining national and international standards. Solar dryers can be classified according to their structure, mode of solar energy collection, drying method (Fig. 1)[11].

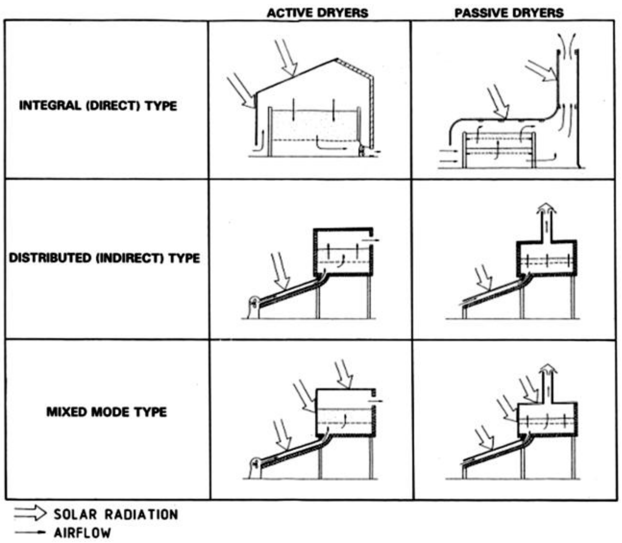

Fig. 1 Classification of drying using solar energy

In this study performance of three different types of natural convection cabinet direct solar dryer chambers, i.e. thin tube chimney type chamber, attic space type chamber, natural draft chamber was evaluated. In direct solar dryers foods to be dried are placed in an enclosed chamber, with a transparent cover over the chamber. Heat is generated by absorption of solar radiation on the product itself as well as on the interiors of the drying chamber [12].

2. Methodology

2.1 Experimental Setup

These dryer setups are fabricated using Mahogany wood and conventional glass. It has a base length and width of 28 Inch and 19 Inch. The base is supported in four 2×2 Inch columns made from Mahogany wood and has a fixed inclination of 18.5^{o} to capture maximum amount of solar radiation at the Chittagong latitude of 22.3475° N. The length and shape of the supporting columns are kept providing the desired inclination of base. These experimental dryers are composed of three chambers (three different types of dryer) each having an internal dimension of 18×8 Inch and separated by 1-inch thick wall. The thin tube chimney type chamber has a hole of 1-inch diameter in the bottom where a flexible rubber pipe of 20 feet length and 1-inch diameter is fitted. The pipe hangs from the rooftop of a three storied building where solar cabinet dryer is placed and it acts as a chimney to provide natural draft. This chimney type chamber is covered with 18×8-inch glass panel (3 mm thick) and a hole of 1.5-inch diameter is made in the topside of the cover. Attic space type chamber has an attic shape provided by two glass covers both inclined at 50^{o} with the horizontal of 18×6 inch and 18×8-inch dimension. These two inclined glass pieces are surrounded with two glass pieces which have a 1.5-inch hole on it. There is an open space above the cover for passing out hot air. Natural convection cabinet is a solar dryer covered with 18×8-inch glass panel. It has two rectangular ventilation port (15×1 inch on the side for air in and 6×1 inch for air out) to provide natural circulation of air across the chamber. Since performance evaluation of these dryers is one of the main concerns so joints and contacts of wood and glass or rubber is properly sealed.

(a) (b)

Fig. 3 Experimental Setup (a) Top view; (b) Side view

2.2 Working Mechanism

In direct solar drying, fruits are placed inside a glazing roof box which has two openings (hot air exit and cold air inlet). It can be called cabinet drying. Some part of solar radiation incident on the glass plate is reflected back to surroundings. The rest part of solar radiation is transmitted into the chamber [12]. The only heating mechanism of these dryers was solar energy. Irradiated solar energy transmitted from sun passes through transparent glass covers of these dryers and is absorbed by the base and foods. So, the temperature of the surface of absorber and food rises. It heats up the adjacent air enclosed in the dryer thus reduces its density. So, hot air rises in the upward direction and leaves the chamber entraining moisture from food to be dried resulting in suction using another port in the lower side. Since radiated energy from sun is absorbed in the dryer but cannot dissipate outside due to greenhouse effect in the chamber, temperature in the dryer rises. So, air in the chamber is less dense. As, this dryer is placed in the roof of a 3 storied building a pipe is used as chimney in dryer 1. The suspended inlet of the pipe is positioned in cool place. So, air flows upward in the pipe due to the pressure difference between drying chamber and pipe inlet. Since no other opening is provided in this chamber thus air flow is only due to pressure difference. In dryer 2 air enters through the circular holes as shown in figure 2 and exits using the gap of two inclined glass plates. As air inlet size is comparatively small wind velocity have minimum effect for this chamber. For dryer 3 air enters using the side opening and exits using through upward opening. Dryer 3 has privilege of natural wind velocity as it has larger openings. Wind velocity has a significant effect in moisture removal from food. In the dehydrating process food losses moisture to adjacent air and air reaches equilibrium with food so moisture removal ceases. Circulating air breaks the equilibrium by carrying the adjacent air away and increase moisture removal rate.

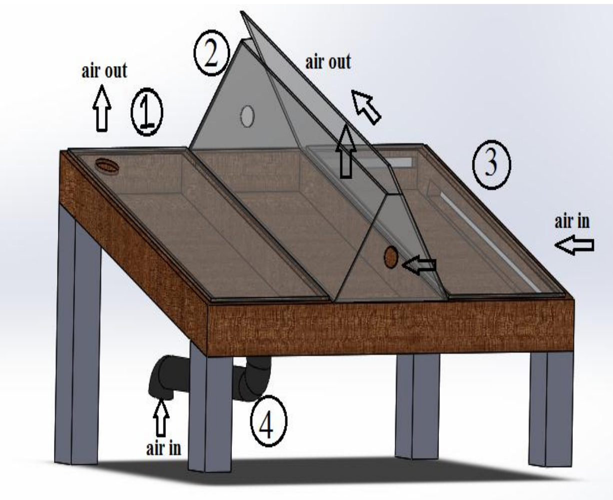

Fig. 4 Constructed dryer 1) Thin tube chimney type dryer 2) Attic space type dryer 3) Natural convection type dryer 4) Chimney.

In order to simplify the evaluation, heating source of this dryers was solar energy during day time (10am to 4 pm). The objectives of the trials are:

- To evaluate dehydration rate of different fruits i.e. apple, banana, guava, pineapple and moisture content at different drying period.
- To evaluate drying rate of different fruits in different chamber at different drying time interval.
- To evaluate the performance of three different types of natural convection cabinet direct solar dryers chamber

3. Data Reduction

The dryer was constructed and tested in the rooftop of Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Raozan, (22.4600° N, 91.9710° E) Bangladesh. The performance of these dryers were evaluated during July-August 2017. For these assessment thirteen data were collected at these intervals from which three data were chosen as follows: first day, highest performance day and last day. All the experiments were done from 10 AM to 4 PM. Apple, Banana, Guava and Pineapple are chosen to compare the different dryer performance and also to check their drying performance. Three pieces of each sample were placed in individual compartments after weighing at 10 AM. At 1 PM and 4 PM the dehydrated samples were weighted again. From these data percentage of moisture lost, drying rate, moisture ratio of Apple, Banana, Guava and Pineapple during drying experiment in different chambers were calculated using the following equation:

Dehydration rate (gm/gm)

Drying rate (gm water/gm dry matter. min)

$$\frac{W_{i-}W_f}{W_i} \times 100 \qquad (1)$$

Moisture ratio

$$\frac{M_t - M_{t+dt}}{M \times DMC \times dt} \qquad (2)$$

$$\frac{M - M_e}{M_0 - M_e} \qquad (3)$$

Where W_i, W_f, are the initial and final weight of the sample. M, M_o, M_e, M_t and M_{t+dt} are the moisture content, initial moisture content, equilibrium moisture content, moisture content at ''t'' and moisture content at ''t+dt'', respectively. The moisture ratio was simplified to (M/M_o) of the ($M-M_e$ / M_o-M_e)[13].

4. Results and Discussion

The data collection period was started 9th April 2017. Usually data was taken in sunny day for getting proper dehydration rate. Some data were avoided because of erroneous data collection technique at the beginning from 9th April 2017 to 23th May 2017. Then the data collecting technique was corrected and data was taken three times in a day such as 10am, 1pm and 4pm. After analyzing dehydration rate of before 1pm and after 1pm the performance of each chamber can be identified.

Banana, pineapple, apple and guava were the food samples. In induced draft chamber, the dehydration rate of pineapple is 56% in which 21% dehydration is occurred before 1pm and 35% dehydration is happened after 1pm. Total dehydration rate of Apple is 54.2% in this chamber in which 20.2% dehydration is completed before 1pm and 34% dehydration is occurred after 1pm. For banana dehydration rate is 46.8% in where 15.6% dehydration is completed before 1pm and 31.2%

dehydration is completed after 1pm.In this chamber, dehydration rate of guava is 46.75% in which 17% dehydration is occurred before 1pm and 29.75% dehydration is completed after 1pm. After analyzing the dehydration rate of the samples of induced draft chamber it is seen that the dehydration rate of pineapple is the highest as water level in pineapple is highest among these four samples and it is 87% .Besides, for guava dehydration rate is lowest as water level of guava is lowest than other samples and it is around 58%.Dehydration rate of apple is lower than pineapple but higher than banana. 84% water is contained in apple and 74% water is existed in banana. Besides, dehydration rate of banana is higher than guava but lower than apple. It is also appeared that total dehydration rate of induced draft chamber is 44.5% in which 13.2% is occurred before 1pm and 31.3% is completed after 1pm.

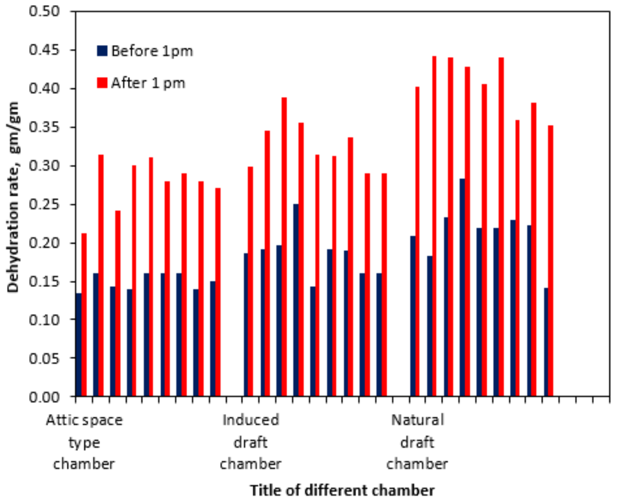

Fig. 5 Dehydration rate of three different direct solar dryer.

After analyzing the dehydration rate of the samples of attic space type chamber it was also seen that the dehydration rate of pineapple is the highest as water level in pineapple is highest among these four samples and it is 87%. Besides, for guava dehydration rate is lowest as water level of guava is lowest than other samples. Dehydration rate of apple is lower than pineapple but higher than banana. Besides, dehydration rate of banana is higher than guava but lower than apple. It is also appeared that total dehydration rate of attic space type chamber is 33.3% in which 11.2% is occurred before 1pm and 22.1% is completed after 1pm.

In natural draft chamber, the dehydration rate of pineapple is 66.33% in which 23.3% dehydration is occurred before 1pm and 43.03% dehydration is happened after 1pm. Total dehydration rate of Apple is 63.8% in this chamber in which 22.4% dehydration is completed before 1pm and 41.4% dehydration is occurred after 1pm. For banana dehydration rate is 53.6% in where 19.8% dehydration is completed before 1pm and 33.8% dehydration is completed after 1pm.In this chamber, dehydration rate of guava is 54.75% in which 20.62% dehydration is occurred before 1pm and 34.13% dehydration is completed after 1pm. After analyzing the dehydration rate of the samples of natural draft chamber it is also appeared that the dehydration rate of pineapple is the highest as water level in pineapple is highest among these four samples. Besides, for guava dehydration rate is lowest as water level of guava is lowest than other samples and it is around 58%. Dehydration rate of apple is lower than pineapple but higher than banana. Besides, dehydration rate of banana is higher than guava but lower than apple. It is also appeared that total dehydration rate of natural draft chamber is 58.9% in which 20.5% is occurred before 1pm and 38.4% is completed after 1pm. It is appeared that total dehydration rate of induced draft chamber is 44.5%, for attic space type chamber dehydration rate is 33.3% and for natural draft chamber it is 58.9%. So, it is cleared from this analysis that the performance of natural draft chamber is best than other two chambers and performance of attic space type chamber is worst. Besides, the performance of induced draft chamber is better than attic space type chamber. It is also seen that dehydration rate before 1pm is lower than after 1pm.Besides; dehydration rate of pineapple is the highest as water level is so much high and for guava is the lowest as water level is low. Dehydration rate of apple is lower than pineapple but higher than banana.

Different fruits have different rate of moisture loss percentage in a day. As shown in Fig. 6 (a) moisture loss rate of each fruits is maximum in natural draft chamber and minimum at attic space type chamber in each of the three days. Moisture loss percentage is minimum for pineapple as it contains maximum amount of water among these four items. Moisture loss percentage is maximum for Guava as it contains less amount of water among these four items.

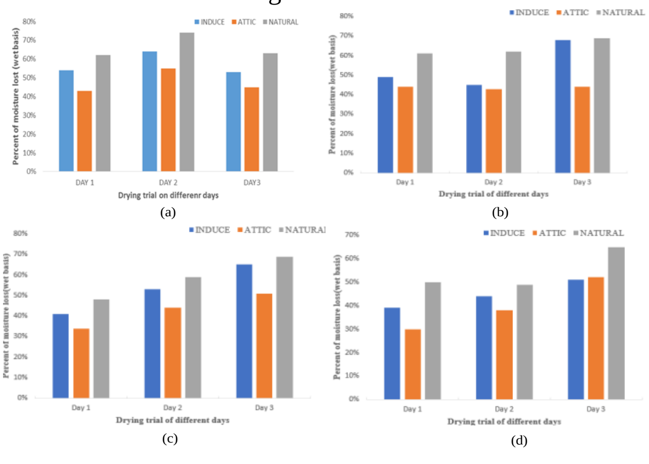

Fig. 6 Moisture loss rate for (a) Apple; (b) Banana; (c) Pineapple; (d) Guava.

Fig.7 shows the drying rate of different fruits (Apple, Banana, Guava) in different chambers with time. First drying rate analyzed from 10am to 1pm and then 1pm to 4pm. It is seen from Fig.7 that drying rate is maximum in natural draft chamber for all the sample. Because maximum air can be passed through natural draft chamber. Drying rate is found maximum at 2nd period of drying time(1pm-4pm). Because temperature was keep rising from 10am and become maximum at mid noon of those days. Drying rate of Apple is maximum as it contains highest level of water and this rate is maximum between 1pm to 4 pm. Drying rate of guava is minimum as it contains lesser level of water. Its drying rate is maximum between 1pm to 4pm. Drying rate of Banana is higher than Guava but lower than Apple because it contains higher quantity of water than Guava but lower amount of water than Apple.

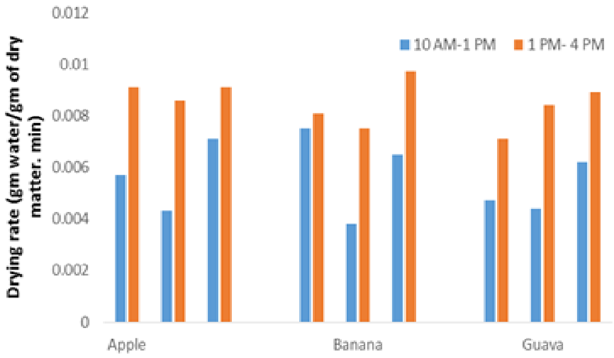

Fig. 7 Drying rate of different fruits in different chambers with time.

Fig. 8 shows the moisture ratio of different fruits (Apple, Banana, Guava) in two different times of 1pm and 4pm. Moisture ratio of the samples was lower at 4pm and higher at 1 pm. Because dehydration rate was increasing higher after 1 pm. Fig.8 indicates more moisture was removed during 1pm to 4pm instead of 10am to 1pm. As well as more convenient chamber was natural draft chamber at which most moisture content was removed from those fruits. Attic type chamber was found less efficient among the three chambers in which moisture ratio was higher for every sample. Induced draft chamber was less efficient than natural type chamber but more efficient than attic type chamber.

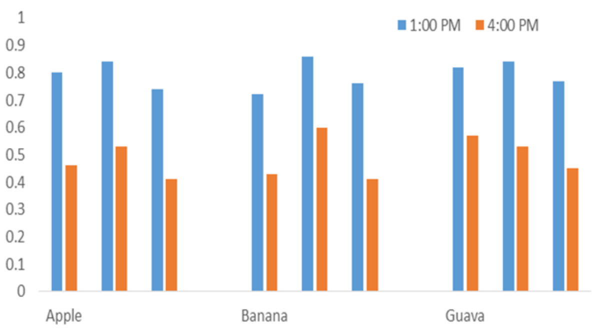

Fig. 8 Moisture ratio of different fruits in different chamber.

5. Conclusion

In the study three different types of natural convection cabinet direct solar dryers chamber, i.e. induced draft chamber, attic space type chamber, natural draft chamber, were used. Performance of natural draft chamber was the best and attic space type chamber was the worst among three chambers. Because the total dehydration rate of natural draft chamber was 58.9% which was highest among the three chamber and 33.3% for the attic space type chamber which was lowest among them. The performance of induced draft chamber was better than attic space type chamber with total dehydration rate of 44.5%. Dehydration rate of pineapple was the highest and lowest for guava among four samples. Dehydration rate of apple was lower than pineapple but higher than banana. Besides, dehydration rate of banana was lower than apple but higher than guava. Drying rate after 1pm was higher than rate of before 1pm. As natural draft chamber was a wooden chamber, so much cheap to make and performance is the best among three chambers, so it can be told that natural draft chamber will be most effective for the coastal area of Bangladesh.

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