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Fabrication and Performance Study of a Direct Type Solar Dryer

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Abstract— Solar energy is used in the solar drying system in order to dry food material loaded as well as to heat up the air, that is useful in utilizing and preservation of more agricultural product. As the natural sun drying has some shortcomings like direct sunlight exposure, pests attack, need of sufficient control and the mechanical dryer cost. To avoid these deficiencies a solar drier is developed. This work represents how the design and construction of a direct type solar dryer is done and its performance has been observed for food preservation. The heated air is passed through the chamber. Simultaneously, through the transparent roof directly solar energy is absorbed by the drying cabinet. For both natural and forced convection drying rate was noted. The dryer performance is also compared with two different modes.

Index Terms— Sun drying, Moisture content, Solar radiation, Drying rate.

1 Introduction

THE food crisis is becoming a great problem for the most of the developing countries as the population is increasing in a great number regardless of territories. This excess population increase affects food balance. Due to limited storage facilities and poor processing methods the quality and quantity of food grains are deteriorating [1]. Food losses reduction during production time is required to keep proper balance between food supply and population growth. In rural areas it is difficult to maximize the food production capabilities of small farmers. As a result drying is considered as one of the main processing methods in sunny areas to conserve food products. After all, conventional open sun drying has some drawbacks. To solve this problem, researchers scientists and have been working to find the best alternate for the past few years. For agricultural goods they developed different types of solar dryers and have progressively worked to advance these dryers. First of all, the question can be faced with the necessity of drying foods using solar energy. The answer is very much simple. The sun is the source of all energy throughout the earth. The energy is easier to get. Though there are some limitations in using the sun as a source of energy for drying, it will help us to overcome the crisis of the source of energy. As we know, Sun is a huge source of energy this energy can be converted into different form of energy. Jain and Tiwari [1] developed a mathematical model about the thermal behavior of open sun drying. They found that the moisture transformation rate of cauliflower and potato slice is significantly high and the prediction of crop temperature, moisture removal rate, and static condition of air temperature are due to ambient conditions. Open sun drying is a time-consuming process and international standard quality would not be reach by it.

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Bala and Woods [2] developed a solar dryer of optimal dimensions using the concept of computer simulation. Brenndorfer [3] improved a technique for drying grains using solar energy where the inlet air is heated and then passed through over grains using a fan.

Zomorodian *et al.* [3] designed, verified, and evaluated an active mixed-mode dryer for drying rough rice. The drying system includes a drying chamber, an inlet and outlet bin, and a plenum chamber. There are two experimental applications of this system. Mass flow rate and discharge interval time were observed by both the first and the second applications and moisture content was examined in the later one. The effect of the mass flow rate and the discharge rate of crop dryinf found very impressive with the maximum efficiency of the system 21.24%, and the energy consumed during the drying process was 6 to 8%. The final moisture content at ambient temperature was 13%.

By satellite solar irradiance is calculated above earth's atmosphere. To derive the consequence at one AU to check solar constant the value is adjusted using the inverse square law.Global solar irradiance is very important to know the intensity of heat energy around the earth.

It is clear from the figure 1 to figure 2 that geographically Bangladesh can take a lot of advantages from the energy that radiates from the sun. Though Dinajpur has the maximum monthly average irradiance, data were collected from Chittagong region only. The energy can easily be used for drying process which will help us to preserve food. The difficulty of preserving food for the huge population is one of the major problems that is faced by almost every developing countries like Bangladesh. So, solar energy can be a good option to solve the problem.

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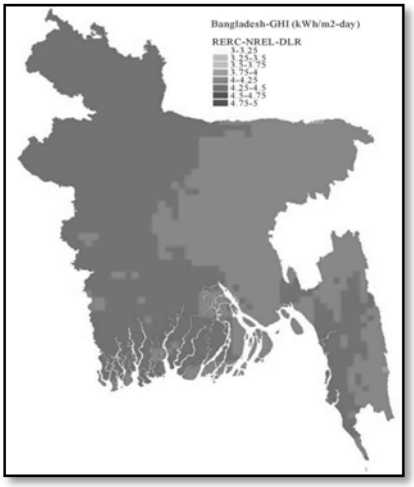

Fig. 1: Global horizontal irradiance in Bangladesh [4].

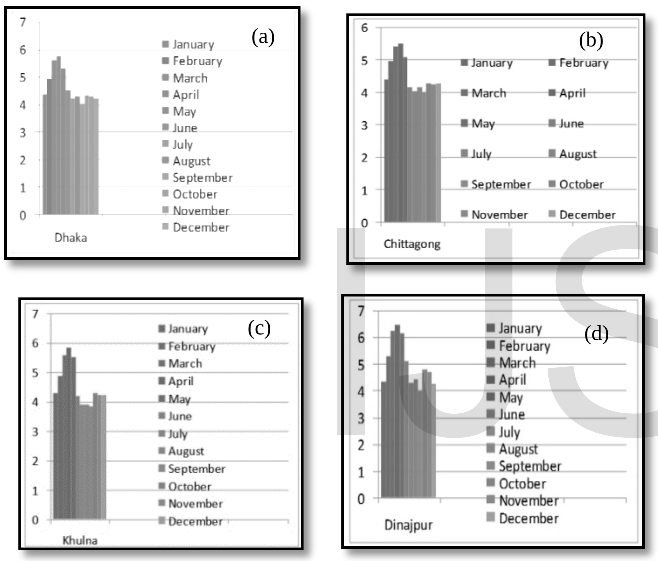

Fig. 2: Monthly average irradiance in different locations of Bangladesh (a) Dhaka, (b) Chittagong, (c) Khulna and (d) Dinajpur [5].

The main objective of the paper is to fabricate a direct active solar dryer and analyzing the performance by solar drying in Chittagong region applying two different modes. It is also extended to determine the efficiency and rate of moisture removing during drying various foods like potato and banana.

2 Design Approach

There are different types of solar dryers mentioned by several researchers such as Direct type, Indirect type solar dryer, Mixed-Mode, natural convection, Forced convection type solar dryer. In this work, a direct type active type solar dryer was fabricated which is commonly used in areas that receive direct sunlight for long periods during the day [6].

In direct type solar drying only the natural movement of heated air is employed. A little amount of solar radiation on the glass cover is reflected back to atmosphere and remaining portion is transmitted within the cabin dryer. Further, a portion of transmitted radiation is mirrored back from the product and the remaining portion is absorbed by the material. As product absorber solar radiation, the temperature of the product increase and therefore the product starts emitting long wave length radiation. The long wave is not allowed to escape to the atmosphere through the glass cover, unlike open sun drying. During this method, the temperature inside the chamber becomes higher. The glass cover also prevents convective losses to the ambient which further become useful for the rise of product and chamber temperature [6]. However, convective and evaporative losses occur from the heated product. So, the moisture is taken away by entering air from below of the chamber and escaping through another gap at the top.

There is a drying chamber in this dryer that is enclosed by glass or plastic made transparent cover. In general the drying chamber is a shallow, insulated box having air-holes in it. These air-holes permit air to enter and exit through the box. On a perforated tray the product samples are placed. Thus, air flows through it and other materials. During passing through the transparent cover solar radiation is converted to low grade heat as it strikes an opaque wall. Due to greenhouse effect this low grade heat is then trapped inside the box. Which stands on the principle of 'Wien's displacement law' "Simply states, the short wavelength solar radiation can penetrate the transparent cover". When the conversion to low-grade heat is done, the energy starts to radiate.

2.1 Drying Mechanism

Heat is necessary to evaporate moisture in the process of drying from the material and flowing air carries away the evaporated moisture. The two basic mechanisms involved in the drying process: the transformation of moisture from the interior to the surface of a product, and the evaporation of moisture from the surface to the surrounding air [7].

The drying is a complex heat and mass transfer process which depends on many external variables and internal variables. The external variables are temperature, humidity and velocity of the air stream. The internal variables are depend on various parameters like surface characteristics (roughness or smoothness of surface), chemical composition (starches, sugars, etc.), physical structure (porosity, density, etc.), and size and shape of products. Moisture movement rate from the inside to the outside air of a product is differs from one product to another, depending on whether the material is hygroscopic or non-hygroscopic. Non-hygroscopic materials can be fully dried but the hygroscopic materials have a residual moisture content. Most of the food products are hygroscopic type materials. This residual moisture may be bound in the material due to closed capillaries or due to surface forces and unbound moisture which remained in the material due to the surface tension of liquid as shown in figure 3 [7].

On the basis of relative humidity of the air the hygroscopic material will absorb either moisture or desorbs moisture , when it is exposed to air. If the partial pressure of water in the surrounding air and vapor pressure of water in the material becomes equal the equilibrium moisture content (EMC = Me) will reach. Under a given set of drying conditions the equilibrium moisture content is the minimum moisture to which the material can be dried. Drying characteristic curves are plotted shown in figure 4. Considering all the requirement an active type solar cooker was designed shown in figure 5.

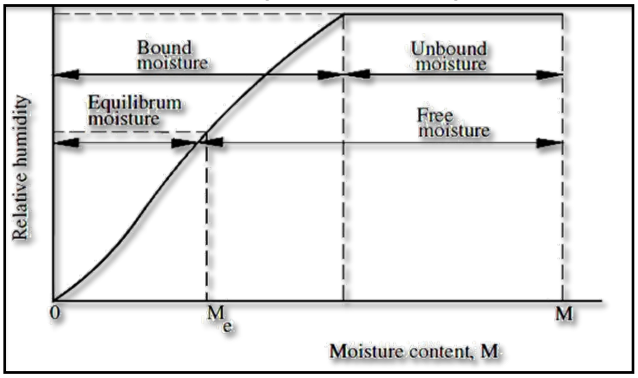

Fig. 3: Moisture content in drying material [7].

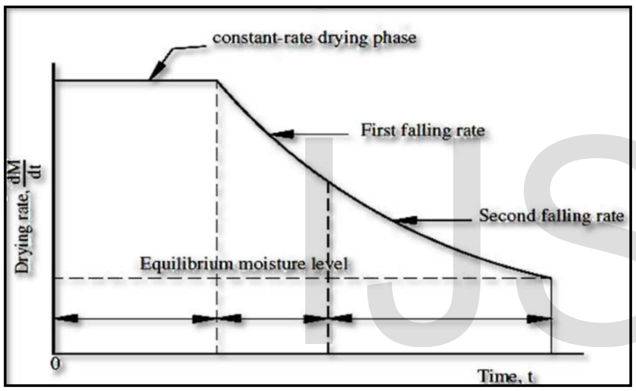

Fig. 4: Drying Rate with time [7].

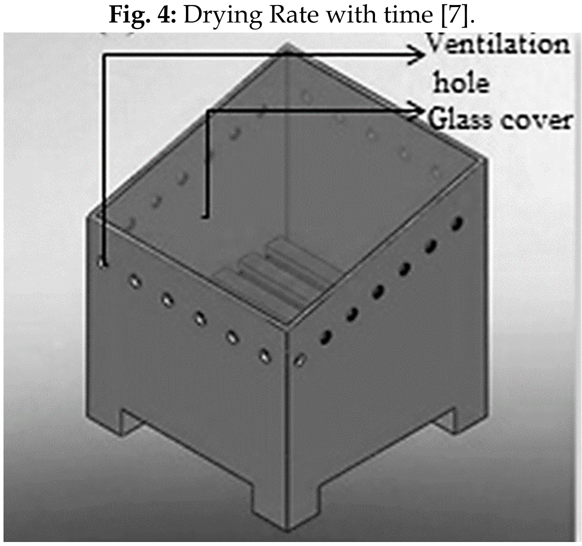

Fig. 5: 3D Model of the proposed solar dryer

2.2 Specifications

The specification for the proposed designed is given in table 1.

Table 1: Specifications for the solar dryer system

Particulars	Specifications
Thickness of insulation to drying box	13 mm cork-sheet
Number of drying trays	1
Size of the drying tray	560 × 560 mm
Solar air heating collector area	0.376 m^2
Overall size of the storage box	660 x 610 x 610mm^3
Type of the fan	12V, DC. Size: 13x13mm^2
Top cover of the box	Glass covers of 4 mm thick
Thickness of the PVC-Sheet	5 mm
Inclination of the solar glass with respect horizontal	25°

3 Fabrication of The Solar Drayer

Natural convection solar dryers and forced convection solar dryers are the major two categories of the dryers. The airflow is established in natural convection solar drier by buoyancy force and in forced convection solar dryers the airflow is established by a fan. This fan can be operated either by electricity, solar module or fossil fuel. Though in natural convection solar drying it is complex to control drying, it requires lower investment when compared with the forced convection.

The materials required to fabricate the solar dryer are wood, PVC sheet, GI sheet, mesh, glass sheet, temperature and humidity sensor, cork sheet, digital display, fan, wire net, hinges, and channels. A wooden frame was made as a base structure with proper measurement. There should be good insulation property inside the frame to prevent heat loss. Cork-sheet was used between the wood frame and PVC-sheet.

Equally spaced holes are drilled around the frame structure to remove the moisture content from the product. Inner frame was colored in black color in order to increase the heat absorption capacity of the dryer. Then the plastic covered trays with rollers were attached. There was a movable back door for putting and removing of food products. A 12 volt DC fan was placed inside to observe the performance of the dryer for forced convection. Glass cover was used on the top of the dryer to receive the solar energy from the sun. Finally, LCD display with temperature and humidity sensor are fitted with the frame to collect time to time data for the performance analysis of the solar dryer with varieties foods. Figure 6 shows the final fabricated direct type solar dryer and the dried potatoes are exposed in figure 7.

(b)

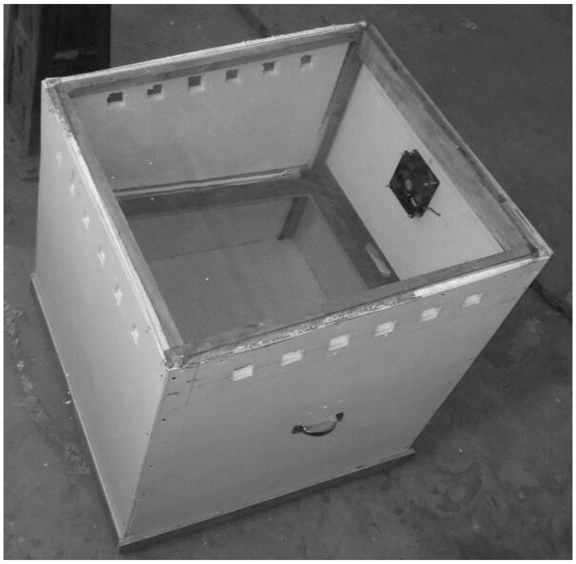

Fig. 6: Fabricated solar Dryer

4 Performance Analysis

A comprehensive detail of balancing of energy, mass, entropy, and exergy was provided by Dincer and Sahin [8], shown in figure 8. It shows that input of drying air to the chamber, the input of moist products to be dried, the output of the moist air after removing moisture from the products and output of the dried products are the main factors to be considered for drying.

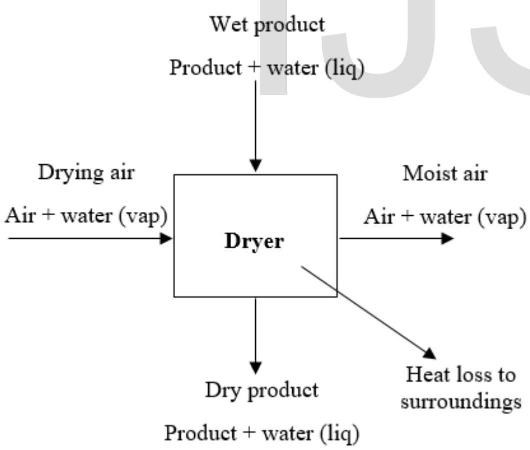

Fig. 8: Schematic illustration of drying systems in terms of input and output terms [8].

The energy balance is obtained by equating total heat gained to the total heat lost by the heat absorber of the solar collector. Therefore,

$$AGt = Q_{cond} + Q_u + Q_{conv} + Q_R \qquad (1)$$

Where A is the dryer aperture area, G is the intensity of the incident solar radiation (3.8 kWh/m²/day for Chittagong), Q_u is the usefull energy collected by the air, Q_{cond} and Q_{conv} are the conductive and convective losses from the absorber respectively, Q_R represents the re radiation from the absorber, t indicates time.

Equation 1 can be also expressed as,

$$AGt = Q_L + mc_p(T_c - T_i) + m_w L_{ev} \qquad (2)$$

Where, Q_{cond}, Q_{conv} and Q_R are combined to one term as Q_L, Q_u is the sum of $mc_p(T_c - T_i)$ and $m_w L_{ev}$.

In the drying system total efficiency is dependent on the two types of thermal energies. While evaporating water from the product a part of energy was absorbed and another part of thermal energy was used in incrementing the temperature of the crop that is lower than the latent heat of evaporation. It is given by the following expression [9, 10]

$$\eta_{ds} = (mc_p(T_c - T_i) + m_w L_{ev})/AGt \qquad (2)$$

Where, c_p is the specific heat capacity, for banana it is given as 3.35kJ/kg°C. m is released vapor mass in kg, L_{ev} is the latent heat of evaporation; m_w *is* the mass of the product determined at time t in seconds.

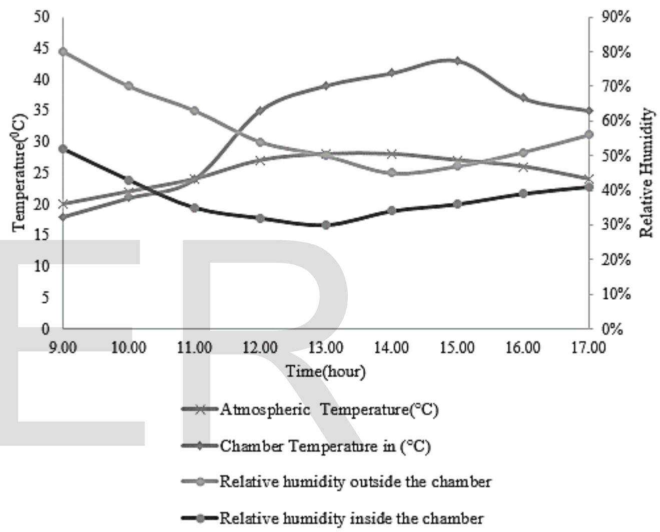

Fig. 9: Temperatures (ambient and chamber), Relative humidity of chamber and ambient temperature from 1st to 4th January 2017 (Natural convection mode)

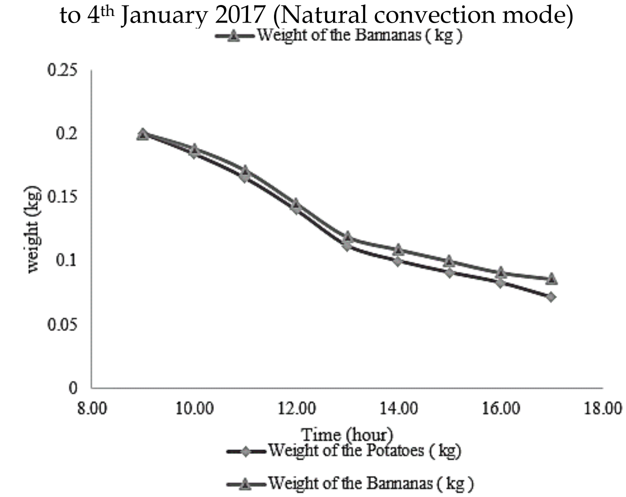

Fig. 10: Weight of the products (potatoes and bananas) when drying (Natural convection mode)

In this work the experimental data were collected in two modes which are natural convection and forced convection. All the required data collected in different time of the day from 9 AM to 5 PM at Chittagong.

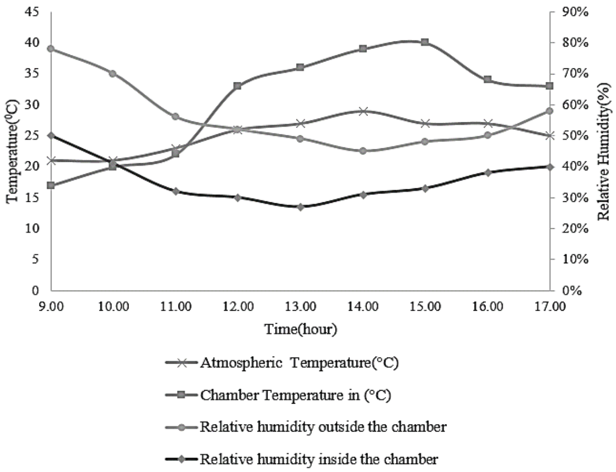

Fig. 11: Temperatures (ambient and chamber), Relative humidity of chamber and ambient temperature from 4th to 8th January 2017 (Forced convection mode)

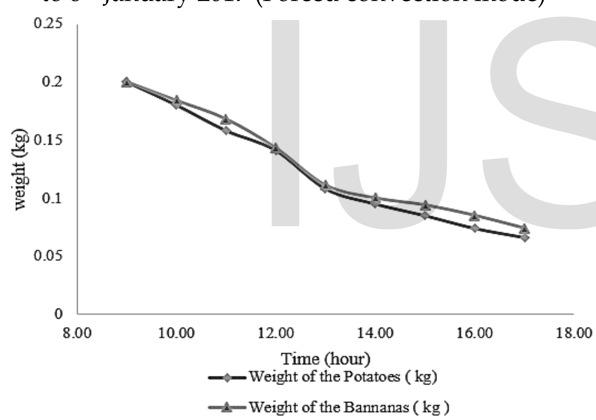

Fig. 12: Weight of the products (potatoes and bananas) when drying (Forced convection mode)

During the 36 hours experiment period, the daily average values of the ambient temperature, drying chamber temperature, ambient relative humidity, and chamber relative humidity were range from 200C to 280C, 180C to 430C,50% to 80% and 30% to 52% in natural convection mode. The graph of figure 9 depicts that the temperature inside the chamber is greater than the ambient temperature, whereas the relative humidity of the chamber is lower than the ambient relative humidity. The weight of the products (potatoes and bananas) decreased rapidly as the moisture is removed through drying is shown in figure 10.

In the case of force convention mode, the DC fan started and the observed data are illustrated in figure 11 and figure 12. The lowest relative humidity (27%) inside the chamber is obtained, which facilitate the drying process. Therefore the weight losing curve is more sloping down than the previous model in figure 12.

The summary of the results are tabulated in table 2 showing the efficiency and comparison of the efficiencies in different modes with different products are shown in figure 13.

5 Conclusion

A direct type solar dryer was designed and fabricated where potatoes and bananas were dried for performance analysis in natural convection and forced convection condition. The temperature and humidity range were observed inside and outside of the chamber. Through the dryer was effective in drying but manipulation of the drying rate was not functional to get expectable food nutrition was. The efficiency in forced convection mode was found greater than the natural convection. However, the fan speed was not controlled with the variation of the drying rate. Thus, the addition of the automatic fan control relating to the drying rate will be beneficial for future improvement. Moreover, the experiment can be done with other food items which need to be stored for a long time. Then it may promote the level of efficiency.

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