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Solar Drying of Fruits and Vegetables

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Abstract— **Drying is a water removal process from foodstuffs commonly used for preservation and storage purposes. Fruits and vegetables are the most important products in agriculture sector. As its contents of nutrition are very high, it has to be preserved. Keeping the products fresh is the best way to maintain its nutritional value. There are many methods for this preservation, but drying process is the most common method of food preservation because it increases the storage life. The moisture content in these products reaches, in some cases, more than 90%. Water content is considered the main reason for microorganisms' growth which leads to putrefaction. In this paper, the performance of a solar dryer for fruit and vegetables, using both natural and forced convection solar dryer, was investigated and compared. Drying rate, weight losses, and removal of moisture content have been studied and analyzed. A comparison between natural and forced convection solar dryers has been done.**

Keywords**— Drying, Solar Energy, Natural Solar Drying, Forced Solar Drying**

I. INTRODUCTION

Solar energy is the most attractive and abundant form of renewable energy sources because it is free, environment friendly and available most of the year. The most common and simplest application of solar energy is to convert it into heat [1]. Nowadays, drying fruits and vegetables have received a great attention from numerous of researchers worldwide because of the high nutrition value contained in this kind of food. Various methods of preservation of fruits and vegetables such as drying, controlled atmosphere, canning, dehydration, refrigeration are being used across the world. According to Hawlader et al [2] solar drying is the most attractive methods used to preserve fruits and vegetables. It can eliminate wastage, increase the productivity of agricultural, and improve the production of fruits and vegetables in term of quality and quantity.

Drying is a process of moisture removal from the product. It can be achieved by various means like freeze drying, mechanical drying, Vacuum drying, thermal drying and chemical drying [3]. The present study belongs to the category of thermal drying, which is used mainly for drying of agricultural products and involves the removal of moisture from the material using thermal energy. Drying of product is a complex combination of heat and mass transfer processes, which depends on external parameters such as temperature, humidity and velocity of the air stream; drying material properties of the agricultural products such as surface characteristics (rough or smooth surface), chemical composition, physical structure (porosity, density) [4].The rate of drying or moisture removal from the interior of the material is hygroscopic and non-hygroscopic. Hygroscopic materials are those which will always have residual moisture content, whereas non-hygroscopic can be dried to zero moisture level.

Drying plays an important role in improving the quality of any products leading to a better marketability of the product and also increases its storage life. When the materials to be dried happen to be agricultural product, the drying becomes much more important, as the chances of spoilage of the product through the activity of microorganisms are very high. As drying is an energy intensive process, use of conventional energy sources may not a desirable choice. When hygroscopic material is exposed to air, it will either absorb moisture or desorbs moisture depending on the relative humidity of the air. The equilibrium moisture content will soon reach when the vapor pressure of water in the material become equal to the partial pressure of water in the surrounding air. The equilibrium moisture is, therefore, important in the drying since this is the minimum moisture to which the material can be dried under a given set of drying conditions. The present study involves a solar dryer, in which the solar energy is collected by solar collectors and transferred to the drying medium which is air. Solar dryers are classified into three main categories, as shown in Figure 1 [5].

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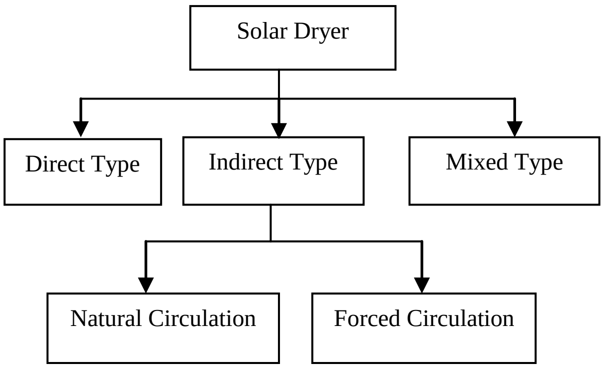

Figure 1: Classifications of Solar Dryers

Sharma et al. [6] experimentally compared the performance of three types of dryers namely; cabinet type of natural convection solar dryer, multistacked natural convection solar dryer and indirect type of multisacked forced convection solar dryer. The comparison was based on removal of the moisture content and the weight loss of chillies before and after drying process. It is conculed that indirect forced convection solar dryer was faster when compared to both natural convection cabinet and the multisacked solar dryer. Cigdem et al.[7] also experimentaly stuided the performance of forced convection solar dryer which was used to dry banana. The dryer was equipped with electric power fan, and auxillary heater inside the drying chamber. Based on evaluation, this type of dryers shortened the drying time and improved the quality of the dried products. Schimer et al [8] stuided the performance of drying system consisting from solar collector covered with plastic sheet and connected to drying tunnel to dry banana. Three fans were used to supply hot air directly to drying tunnel. The banana to be dried were spread in one layer on plastic net in drying tunnel to receive energy from both hot air supplied by collector and the incident solar radiation.The results showed that drying bananas using this dryer took shorter time which is 5 days compared to natural sun drying which needed 5-7 days. Hawlader et al. [9] compared the drying process using natural convection solar dryer and forced convection solar dryer. Mass and moisture content of the apple, guava and papaya with different thickness were analyzed during the experiment. It is concluded that the drying rate of forced convection dryer is higher than that for natural convection dryer.

Incident solar radiation affects the performance of the solar dryers. Hassanain [10] examined the effect of incident solar radiation on the temperature of solar collector and drying chamber as well as the drying time.

The experimental results revealed that the temperature inside the solar collector increased with solar radiation. Therefore, Forced convection solar dryer needed shorter time to perform the task compared to natural convection one. This paper aims to study the performance of solar dryer for fruits and vegetables, and to analyze the moisture content loss and weight loss (mass of the material as a function of time) of fruits during the drying process by comparing with natural convection and forced convection solar dryers.

II. Solar Dryer: Experiments

Proper design for the solar dryer must be implemented in order to achieve the objectives of the research. The schematic diagram of the solar dryer used in this project is shown in Figure 2.

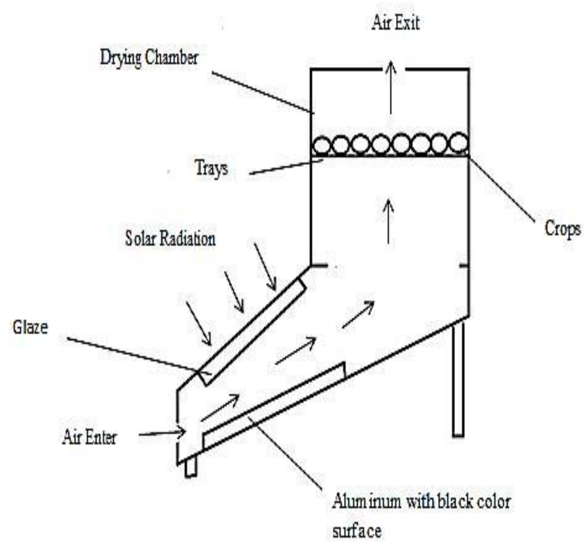

Figure 2: Schematic Diagram of the Solar Dryer used

This type of solar dryer can be operated both in natural and forced convection. When an experiment is carried out for force convection, the blower is placed so that the air is forced to flow in the dryer.

The body of the dryer is constructed using the plywood so that the heat losses will be less. A single glass cover with 0.04 m² area is use to trap the heated air from the solar radiation. In the solar panel, there is absorber plate used was made from aluminium sheet coated with black paint, as shown in Figure 3. List of the material used with prices are shown in Table 1.

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As the air is heated by the solar radiation, it flows from the solar panel to the drying chamber as shown in the schematic diagram, Figure 2. The fruits or the vegetables are placed on the trays in the drying chamber for the drying process. The hot air will flow and dry the fruits and vegetables that are in the drying chamber.

Figure 3: The complete Solar dryer

The solar collector is primarily used to collect the heat from the sun and supply it to the drying chamber. The absorber plates in the solar air collector are metal sheet and aluminum foil with black color surface. LP02 pyranometer was used to measure the incident solar radiation. Thermocouple was used to measure the temperature. Milligram weighing scale is used to weigh the specimen`s weigh before and after it undergoes drying process. For the forced convection solar dryer the air is circulated by the blower. This blower forces the air to circulate in the solar dryer. Stop watch was used to measure the time of drying process. The fruits and vegetables that used are apple, orange and mango with different thickness of slices of 5mm, 10mm and 15mm, as shown in Figure 4. The amount is about 1 kg and will place on the tray inside the drying chamber for the drying process. The purpose of using different thickness is to investigate the effect of the thickness on the drying rate.The specimens were dried and tested for 7 hours, and the experimental data was taken every 30 minutes

Table 1
List of materials that use to build the dryer with prices

Materials	Quantity	Price
1) Playwood with 10mm thickness	1	RM 110
2) Glaze with 0.2mm thickness	2	RM 30
3) Iron string for rack	1	RM 5
4) Aluminium Foil	1	RM 10
5) Black colour spray	1	RM 7
6) Blower (fan)	1	RM 20
Total		RM 225

Figure 4: 5mm, 10mm, and 15mm slices of apple

III. Mathematical Modelling Of The Dryer

A. Moisture Content

Moisture content of fruits and vegetables can be calculated using equation 1, where Mc is Moisture content of the product, (g water / g dry mass) Mt is Mass of the product at time t, g and Mb is Bone dry mass, g.

$$Mc = \frac{Mt - Mb}{Mb} \quad (1)$$

B. Amount of Moisture to be removed from the Product

It can be calculated using equation 2 where, (Mw) is the amount of moisture to be removed from product, (Mi) is Mass of the product before drying, (Mf) is Mass of the product after drying,

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$$Mw = \frac{Mp\ (Mi - Mf)}{100 - Mf} \quad (2)$$

C. Quantity of heat needed to evaporate the H2O

It can be obtained using equation3, where Q is Amount of energy required for drying process, kJ; hfg = Latent heat of evaporation, kJ/g H2O.

$$Q = Mw * hfg \quad (3)$$

D. Useful Energy From Solar Collector

Where, FR is heat removal factor of the collector, and (It) is the incident solar radiation [W/m2].

$$Q_U = F_R A_C [I_t(\tau\alpha) - U_L(T_i - T_\alpha)] \quad (4)$$

IV. Results And Discussion

A. Experimental Results for Weigh Loss

Forced convection solar dryer showed better results than natural convection solar dryer in term of weight loss. The highest weight loss occurred with slices thickness 5mm for apple, mango, and orange as shown in Figures 5, 6, and 7.

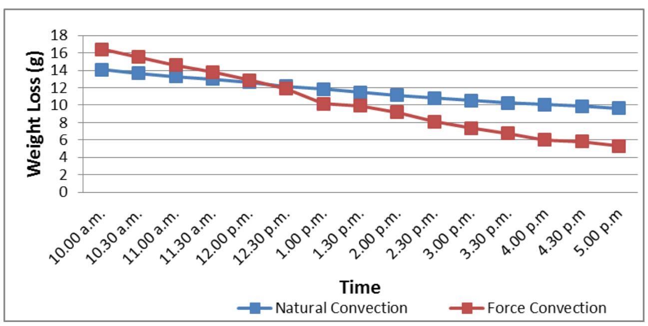

Figure 5: Weight Loss of apple with thickness 5mm with time

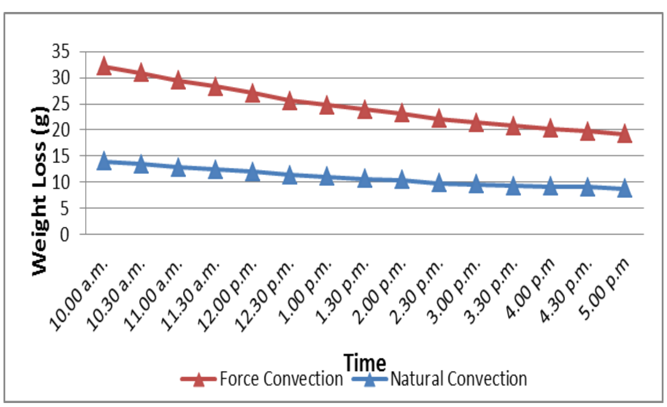

Figure 6: Weight Loss of orange with thickness 5mm with time

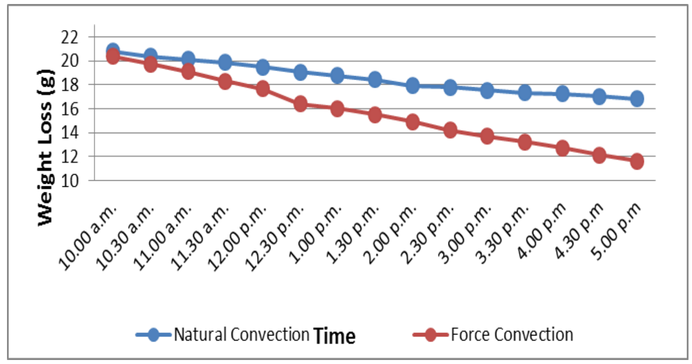

Figure 7: Weight Loss of mango with thickness 5 mm with time

B. Experimental Results for moisture content

The moisture content of fruits and vegetables was decreasing with time in all experiments due to solar incident radiation. It was observed that the drying rate became faster at high moisture content. Forced convection dryer showed also better result in term of removal the moisture content, and the drying process was faster than natural convection. The experimental result showed that the highest moisture content loss occurred to 5mm slices as well, as it shown in Figure 8, 9 and 10.

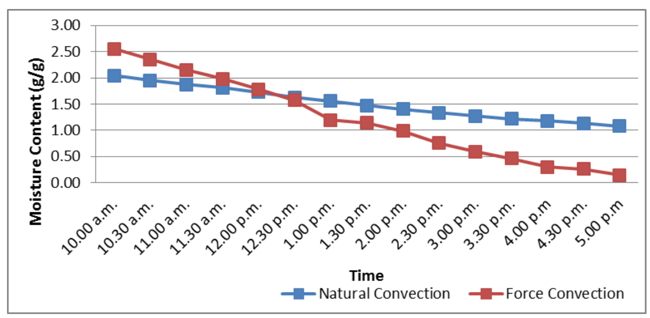

Figure 8: Moisture content of apple with thickness 5mm with time

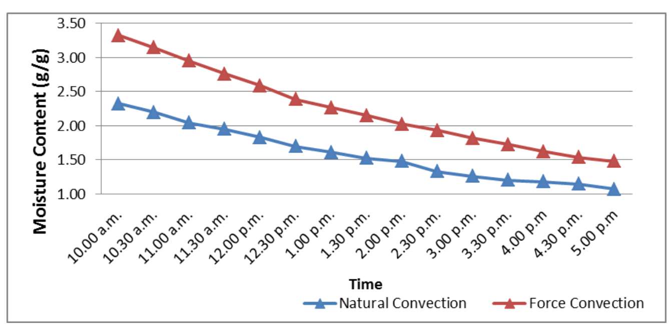

Figure 9: Moisture content of orange with thickness 5mm with time

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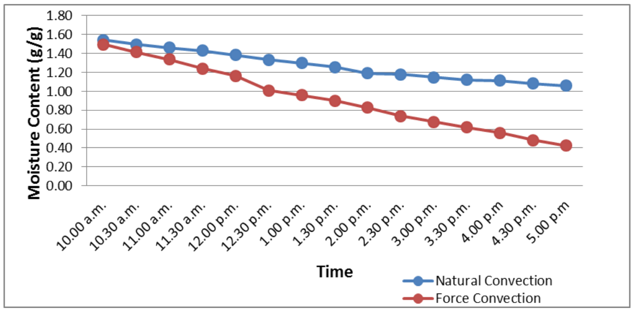

Figure 10: Moisture content of mango with thickness 5mm with time

The weather conditions such as ambient temperature, incident solar radiation, and relative humidity are important factors that affect the performance of the solar dryer. For instance, low ambient temperature will increase the convection heat transfer between the whole dryer body and the ambient air which increases the heat loss to the surrounding. High incident solar radiation will shorten the time of the drying process due to increase the temperature inside the drying chamber. Ambient temperature, incident solar radiation, and relative humidity of the experiments are shown in figure 11, 12, and 13 respectively.

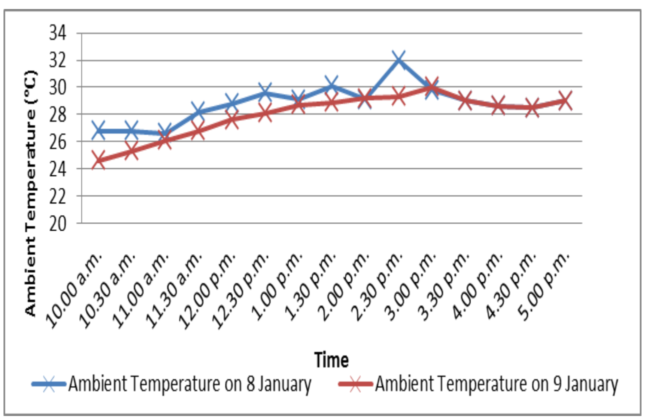

Figure 11: Ambient Temperature on both days

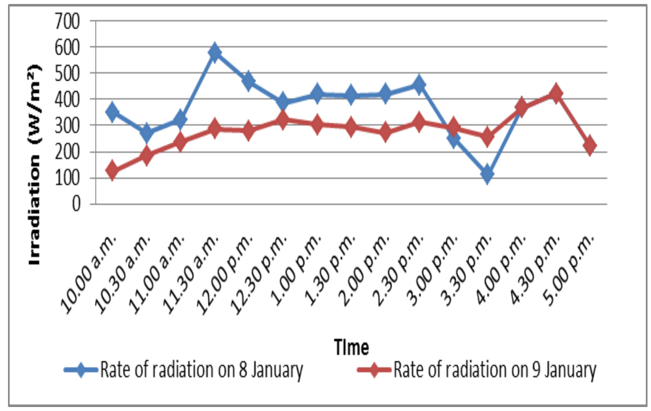

Figure 12: Irradiation on both days

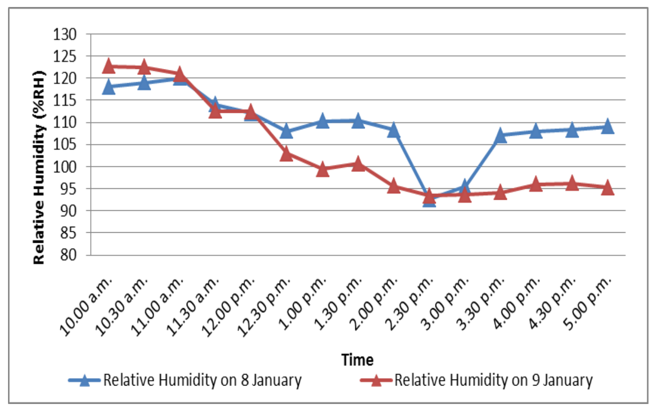

Figure 13: Relative Humidity on both days

V. CONCLUSION

Drying is the process of moisture removal from the product. Unlike open sun drying method, Solar drying system is an enclosed system that can keep the food safe from damage from birds, insects, microorganism, pilferage, and unexpected rainfall. This paper aimed to study the performance of solar dryer for fruits and vegetables, and to analyze the moisture content loss and weight loss of fruits during the drying process by comparing with natural convection and forced convection solar dryers.

It is concluded that the performance of the drying process in the forced convection solar dryer is better compared to natural convection solar dryer. This can be attributed to the forced circulation of air which increases the rate of heat exchange between the air and the product. There are some factors that can affect the drying performance namely; the ambient temperature, rate of radiation received by the solar collector, the relative humidity of air and the wind speed of air.

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