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Performance Analysis of a Greenhouse Dryer

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Abstract: The performance of a natural greenhouse dryer was investigated using three different products: tomato, okra and banana and analyzed the main parameters. Drying temperature, relative humidity correlation with solar radiation, reduced weigh measurement, moisture contents of the products, and drying efficiency of the dryer were measured. In drying temperature measurement results, while the open sun drying is around 40°C, the greenhouse dryer reach 50°C as a maximum result for all three test products. In relative humidity measurement session, it is almost the same in relative humidity inside and outside of the greenhouse dryer. Reduced weight measurement shows the time savings 3hrs for okra and banana, 2hrs for tomato in 9hrs testing time. Additionally in moisture reduced measurement, GH dryer is 20% better for moisture removing in tomato, 10% in okra and banana. In the measurement of dryer efficiencies, it took 3% in okra and tomato, 7% in banana more efficient than the open sun drying.

Keywords: Drying Temperature, Reduced Weight, Drying Efficiency, Relative Humidity.

I. INTRODUCTION

Fresh fruits and vegetables are not only seasonal but also highly perishable since the moisture content is more than 80%, they are classified as highly perishable commodities quality attributes and some could likely result to total waste. The postharvest losses in vegetables has been estimated to be about 30-40% due to inadequate postharvest handling, lack of infrastructure, processing, marketing and storage facilities. Drying is an excellent way to preserve food. Open sun drying of crops and other food stuff has been in practice since time in memorial. This is the most common method of drying. However, the method contaminates by exposing it to dust, excreta from birds and subjects it to destruction by birds, blowflies' larvae and grazing animals. This leads to significant losses. The process of open sun drying is usually slow and in most cases, it is unstable moisture content that are conducive for micro-organisms proliferation, and it becomes a source of food poisoning at sometimes. The process is also highly labor intensive, time consuming, and requires a large area. Therefore, this paper focused on investigating the Greenhouse solar dryer as an alternative solution to all the drawbacks of open sun drying. The improvement of the drying process using the Greenhouse solar dryer will lead to reduced crops losses as well improved quality of the dried products.

II. METHODOLOGY

The solar dryer has the shape of a home cabinet with tilted transparent top. The angle of the slope of the dryer cover is 30° for the latitude of Yangon. It is provided with air inlet and outlet holes at the front and the outlet hole is at higher level. The capacity of 1kg is accepted for the GH solar dryer. The amount of moisture to be removed from a given quantity of wet products, the quantity of air needed for drying, daily solar radiation to determine energy received by the dryer per day and air velocity for the calculation of air vent dimensions were considered in the design of the natural convection solar dryer system.

A. Design of Dryer Dimensions

By applying the Psychrometric chart with DBT = 40°C and RH = 20%, the specific volume of dry air is $\rho = 0.9 m^3 kg^{-1}$.

$$\rho = \frac{m^\circ}{V^\circ} \quad (1)$$

By these relationship, the required volume of air to remove the moisture loss from the product is

$$V^\circ = 6.61 \times 10^{-6} m^3 s^{-1}$$

From the experimental result, recorded maximum wind speed (v_w) is 3km/h by anemometer. Therefore, the inlet air-hole dimension for forced convection is

$$A = \frac{V^\circ}{v_w} \quad (2)$$

Thus, the circle diameter is 3.3×10^{-3} meter or (0.13 inches). In natural convection, the inlet air hole diameter is taken 6 inches relating to the size of dryer. The 6 inches diameter is also taken for the outlet air hole dimension. In this design, two holes in 3 inches diameter are taken concerning with the width of the dryer instead of one hole in 6 inches diameter.

The quantity of heat needed to evaporate the amount of $m^{\circ} = 9.26 \times 10^{-3}$ gs^{-1} is

$$Q = m^{\circ} \times h_{fg} \quad (3)$$

The latent heat of vaporization of the product is

$$h_{fg} = 4.186 \times 10^{3}[597 - (0.56 \times T_{pr})] \quad (4)$$

where,
T_{pr} = product temperature
h_{fg} = 2405kJ/kg
Q = 721.5 kJ

The cover plate is constructed with 1mm thick Plexiglas which is transparent. The thermal conductivity of the cover is 0.2 $Wm^{-2}K^{-1}$. Cast iron mesh is fixed for the test products.

B. Solar Radiation

The rate at which solar radiation is striking a surface per unit area of the surface is called as the total solar irradiation on the surface. This is given by:

$$I_{i\theta} = I_{DN}\cos\theta + I_{d\theta} + I_{r\theta} \quad (5)$$

where,
$I_{i\theta}$= Total solar irradiation of a surface, W/m^2
I_{DN}= Direct radiation from sun, W/m^2
$I_{d\theta}$ = Diffuse radiation from sky, W/m^2
$I_{r\theta}$=Short wave radiation reflected from other surfacesW/m^2
θ = Angle of incidence, degrees

1. Direct radiation from sun (I_{DN})

Direct radiation from sun (I_{DN}) is

$$I_{DN} = A.\exp\left(\frac{-B}{\sin\beta}\right) \quad (6)$$

where, A and B are the apparent solar radiation

2. Diffuse radiation from sky, (I_d)

The diffuse radiation from a cloudless day is calculated by;

$$I_d = C.I_{DN}.F_{WS} \quad (7)$$

where, C is a constant for a cloudless sky for an average day of a month, F_{WS} is a function of the orientation of the surface and it is equal to:

$$F_{WS} = \frac{(1 + \cos\Sigma)}{2} \quad (8)$$

3. Reflected short-wave solar radiation, I_r

The reflected short-wave solar radiation is

$$I_r = (I_{DN} + I_d)\rho_g F_{WG} \quad (9)$$

where, ρ_g is the reflectivity of the ground or a horizontal surface from where the solar radiation is reflected on to a given surface and F_{WG} is view factor from ground to the surface.

The angle factor F_{WG} in terms of the tilt angle is given by

$$F_{WG} = \frac{(1 - \cos\Sigma)}{2} \quad (10)$$

where, Σ is the tilt angle.

III. RESULTS AND DISCUSSION

In this section, dimensions of greenhouse dryer, experimentation, drying temperature, relative humidity, reduced weight, moisture content of the products and drying efficiency are investigated. The results obtained are presented in the subsequent sub-sections.

A. Dimensions of Greenhouse Dryer

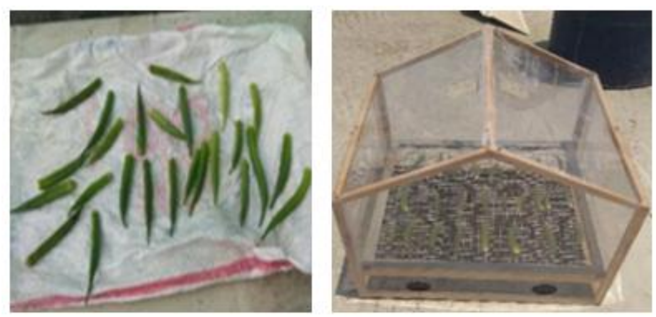
The dimensions of the Greenhouse dryer is shown in Table1. The test product capacity is 1kg, and two inlet air holes and two outlet air holes are made at the dryer.

Table 1. The dimensions of the Greenhouse dryer

Parts	Dimensions in meter
Squared box	(1.016×1.016×0.508)m
Inlet air hole diameter	(0.0762) m×2
Outlet air hole dimension	(0.0762×0.0762) ×2
Cast Iron mesh height	0.1524 m from base plate
Test product capacity	1kg

B. Experimentation

Experiments were carried out on May 3, 4 and 5 at Oak kyin quarter, Innsein, Yangon (latitude 16.81 and longitude 96.16). On the 3rd May, 307.1 grams of Okra was tested and recorded the data of temperature, relative humidity, air velocity and weight measurement comparison to the open sun drying.



(a) (b)

Fig1. Experimentation on Okra, May 3(a) OSD and (b) GHD.

(a) (b)

Fig2. Experimentation on Tomato, May 4 (a) OSD and (b) GHD.

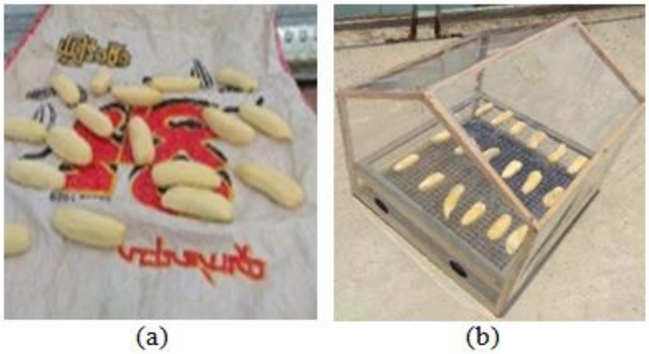


Fig3. Experimentations on banana, May 5(a) OSD and (b) GHD.

During second day, 843.9 grams of tomato was tested and recorded the data. And at the final day, 1316.7 grams of banana was tested. Observations were taken in every hour from 8am to 5pm and all are taken the comparison with the open sun drying. Figs. 1 to 3 show the experimentation on test products of okra, tomato and banana.

C. Results of Drying Temperature Measurement

The distinct parameter for measuring the effectiveness of the drying process is temperature measurement. It can also detect the variations to the heat stored and moisture state. Test results are shown in Figs. 4 to 6.

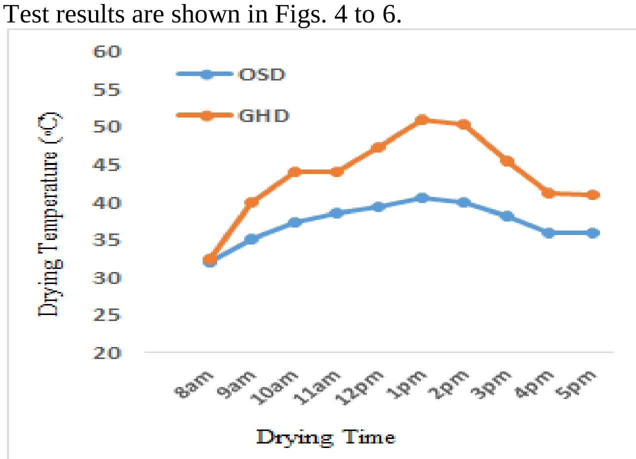


Fig4. Temperature Measurement Results, (May 3, Okra)

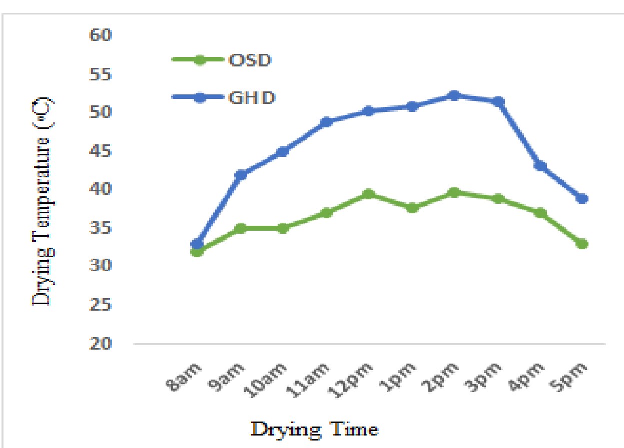


Fig5.Temperature Measurement Results(May4, Tomato).

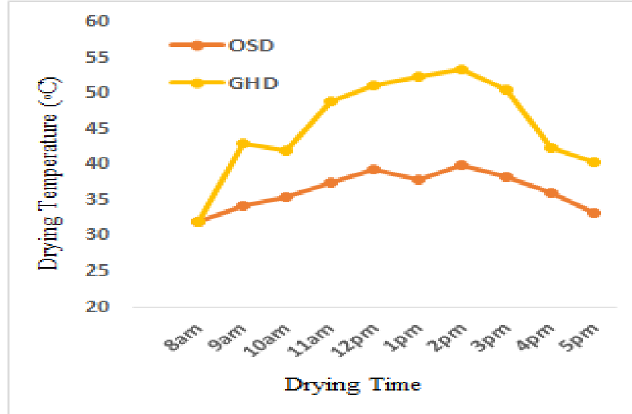


Fig6.Temperature Measurement Results(May5, Banana).

The temperatures of OSD and GHD are the same only at the starting time of 8am. After taking an hour, the temperature in GH dryer is leading efficiently to OS drying by 5℃ as minimum. It reached the highest temperature of 51℃ in GH dryer when the ambient at around 38℃. At the end of the day at 5pm, GH dryer's temperature reached to around 40℃ when OS drying temperature at around 33℃ for 3 days with different test products. From the Figs. 4 to 6, the variants in temperature between Greenhouse drying and open sun drying is significantly different. All the results show that the maximum temperature difference reach around 15℃. As checking the greenhouse dryer's design constraints, it was assumed to get the efficient temperature of 30 percent. Thus, the experimental result is valid to the designed GH dryer. The maximum temperature is reached at the point of accepting the great solar radiation, it was around 1pm. Thus, the temperature of the Greenhouse dryer is the greatest at solar noon relative to the open sun drying.

D. Results of Relative Humidity Measurement

Relative humidity (RH) measuring parameter is the must-do process to know the carrying of vaporized moisture by the outside air from the inside of the greenhouse dryer. If it isn't get the enough ventilation to the process, it would be much moisture trap inside it. So, the drying process could be slower and it could affect the performance of the dryer. Relative Humidity Measurement Results are shown in Figs. 7 to 9.

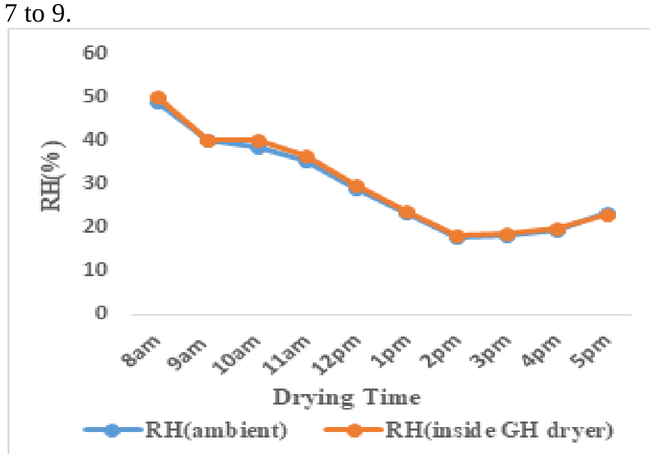


Fig7. RH Measurement Results (May 3, Okra).

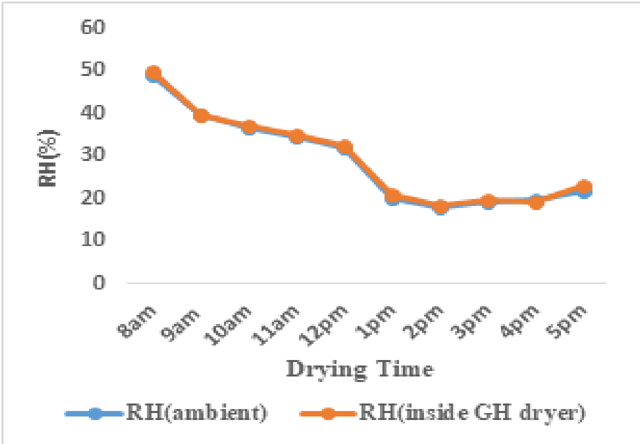


Fig8. RH Measurement Results, (May 4, Tomato).

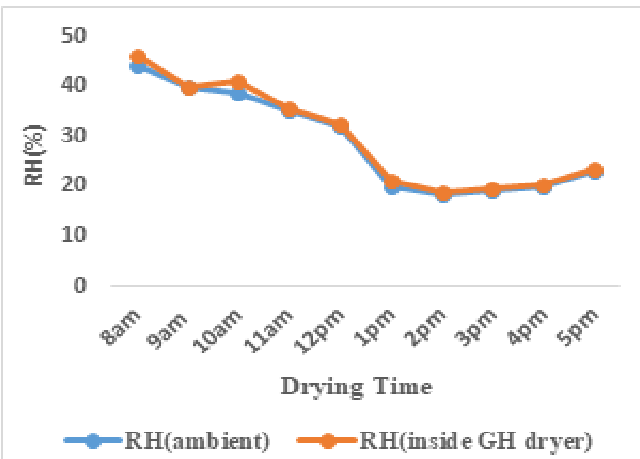


Fig. 9. RH Measurement Results, (May 5, Banana).

RH measurement results were taken with the multi-meter test. According to the test results, at the start of the day, the maximum RH is 50% and then it decreased to around 23% after the test. According to the test results, it is almost the same in relative humidity variant inside the greenhouse dryer and open sun drying in ambient. It means that there isn't much moisture trap inside the greenhouse dryer. Thus, the greenhouse dryer is performing well for the carrying of the vaporized water from the test products. The RH test data show the great advance to the performance of the dryer.

E. Results of Reduced Weight Measurement

Reduced weight measurement results are shown in Figs. 10 to 12. Drying was performed from 8am to 5 pm for Okra, Tomato and Banana on May 3rd, 4th and 5th respectively. After 9hrs, weight of Okra reduced from 307.1 to 147.5 grams in open sun drying. However, it reduced from 307.1 to 117.6 grams in green house drying. It is observed that the net weigh reduced of 30gram in GH dryer over OS drying. The experimental results for Tomato also has the net weight reduced of 21.1 grams and Banana has 69.2 grams. These Figs.10, 11 and 12 show the time effectiveness of the greenhouse dryer comparison to the open sun drying relative to the reduced weight measurement data during 9 hrs. It saves 3hrs for okra, 2hrs for tomato and 3hrs for banana.

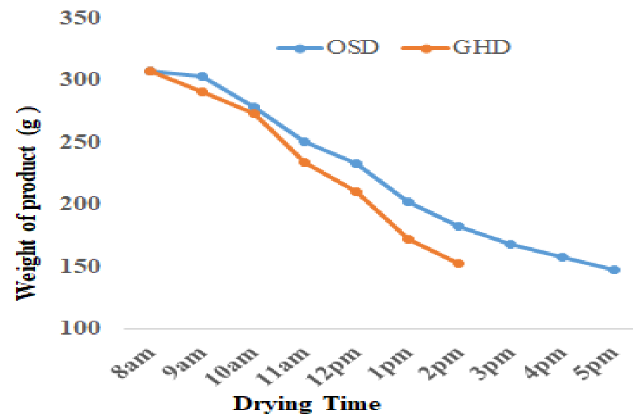


Fig10. Reduced Weight Measurement Results (May3, Okra).

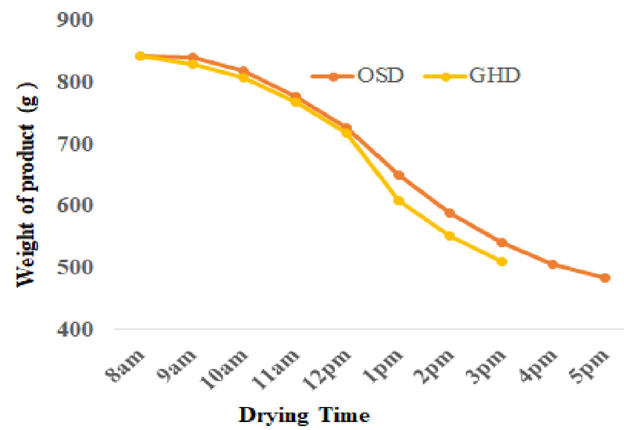


Fig11. Reduced Weight Measurement Results (May 4, Tomato).

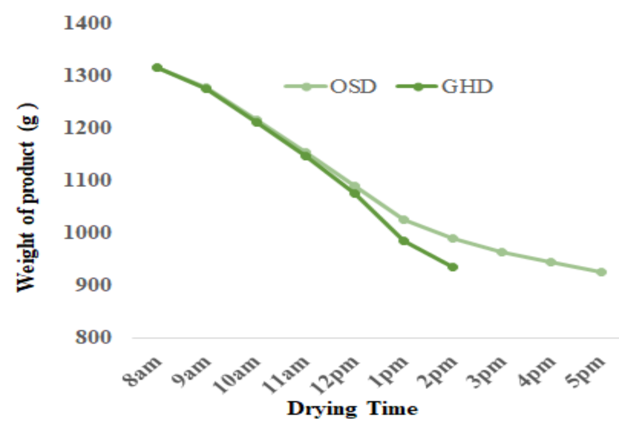


Fig.12. Reduced Weight Measurement Results (May 5, Banana).

F. Results of Moisture Content of the products

The average initial moisture content of fresh okra, tomato and banana is 80, 95 and 80 percent respectively. The final weight of these three products in 9hrs is 117.6, 463.1 and 857.1 grams respectively. The moisture content of the products for OSD and GHD is shown in Fig. 13. The Fig. 13 is plotted with the comparisons of Initial Moisture Content (IMC) and Final Moisture Contents (FMC) in open sun drying (OSD) and Greenhouse dyer (GHD) for three products. It can be clearly seen that depending upon the weight reduced and initial moisture content that can affect the final moisture contents. In test result, green house dryer took moisture removing of 20% in tomato, 10% in okra and banana better than the open sun drying during the drying time 9 hrs.

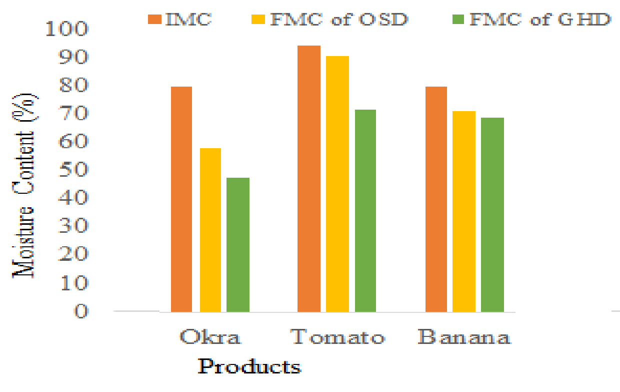


Fig.13.Moisture Content Comparisons of OSD and GHD.

G. Results of Drying Efficiency

The Fig14 shows the drying efficiency comparisons to OSD and GHD. The variable is the weight reduced by the greenhouse effect. The greater the weight difference leads to better drying efficiency. According to the test results, it took 3% in okra and tomato, 7% in banana more efficient than the open sun drying.

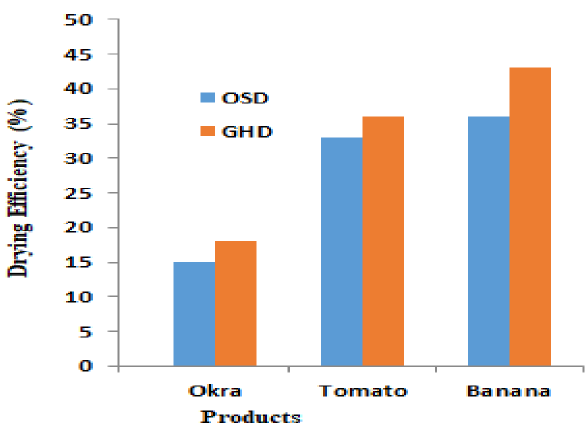


Fig.14. Drying Efficiency Comparison of OSD and GHD.

IV. CONCLUSION

The performance of the Greenhouse dryer was tested with three products how it is working properly. The comparison resulted show clearly on the difference of open sun drying and greenhouse drying. Experimental measuring parameters focused on drying temperature, relative humidity measurement, reduced weight measurement results on OSD and GH dryer. In drying temperature measurement result, the maximum temperature difference on OS and GH drying is 15°C thus the drying temperature is 30% better in GH dryer. Reduced weight measurement shows the time savings 3hrs for okra and banana, 2hrs for tomato for the experimental time of 9 hrs. In RH measurement session, it is almost the same in relative humidity inside and outside of the GH dryer. It mentions that moisture didn't trap inside the Greenhouse dryer. Additionally in moisture reduced measurement, GH dryer is 20% better for moisture removing in tomato, 10% in okra and banana. In drying efficiency results, the greater the weight difference leads to better performance in the drying process. According to the test results, the greenhouse drying is better 3% in okra and tomato, and 7% in banana than the open sun drying during 9hrs testing time. All the test results show separately positive shades how the GH is sufficient over open sun drying.

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