Performance Analysis of Drying Chamber on Effect of Moisture Content

NANDAR WIN¹, MYAT MYAT SOE², THEIN MIN HTIKE³

¹Dept of Mechanical Engineering, Mandalay Technological University, Mandalay, Myanmar, Email: nandarwin985@gmail.com.
²Dept of Mechanical Engineering, Mandalay Technological University, Mandalay, Myanmar, Email: myatmyatsoe.mtu@gmail.com.
³Dept of Mechanical Engineering, Mandalay Technological University, Mandalay, Myanmar, Email: ktmgktmg@gmail.com.

Abstract: This paper presents the design, construction and testing of drying chamber in mixed mode solar dryer for mango. Solar dryer is made up of wood, plywood, and acrylic is used for cover to transparent. In this drying chamber, two layers are fitted. Experiment location is Mandalay, Myanmar (Long 96.1°E, Lat 21.98°N) and drying chamber received solar irradiance about (893 W/m²) and ambient temperature is (40°C) in May. Solar collector area is (1.49 m²). According to this data, this system can reduce initial moisture content of mango 72% (w.b) to final moisture content 8% (w.b) for first tray and 72% (w.b) to 13% (w.b) for second tray. System has been used drying mango capacity is 813.4 g/tray for first tray and 911.4 g/tray for second tray. In addition, the system can remove potato’s initial moisture content 81% (w.b) to final moisture content 5% (w.b) for each tray. The used of drying capacity for potato in drying chamber is 646.8g/tray for first tray and 600.6g/tray for second tray. Hence, drying chamber efficiency is 73% in May.

Keywords: Drying Chamber, Mixed Mode Solar Dryer, Moisture Content, Mango And Potato.

I. INTRODUCTION

The principal aim in a drying operation is the supply of heat required to provide the best product quality with minimum energy consumption. There are two techniques for drying of food and vegetable, namely, open sun drying and solar drying in a drying system. Traditional open air sun drying process is one of the oldest, simplest and widely practiced by local farmers in the rural areas. The process requires relatively low capital investment, large drying area, is time consuming, and is generally unhygienic.[1] In order to solve the problem, solar dryer have been proposed to utilize free, renewable and non-polluting energy. Solar dryers are mainly used for drying process. The purpose of drying is to reduce its moisture content to a level that prevents its deterioration. Preservation of product is essential for keeping them for a long time without deterioration.

In comparison to natural sun drying, solar dryers generate higher temperature and lower relative humidity. [2] Heat absorbed by the product supplies the energy necessary for the vaporization of water from the surface of the product. When the absorbed energy has increased to the limit that water vapor pressure of the product moisture will be higher than the vapor pressure of the surrounding air, water from the surface of the moist product starts to vaporize. Solar dryers may be classified according to the mode of air flow as natural convection (passive) and forced convection (active) dryers. Natural convection dryers do not require a fan to blow the air through the dryer. Solar drying may also be classified into direct, indirect and mixed-modes. Types of solar dryer explain in Fig.1 to 3. [2] For operating the solar dryer in direct mode, the material is directly exposed to solar radiation. Cold air enters through the ventilation holes beneath the trays, gets heated and takes the moisture out through the slits. This dryer as such works in direct mode. [3] Indirect solar drying or convective solar drying is the new technique of product drying. It is very efficient method than the direct type of solar drying. In this method the atmospheric air is heated in flat plate collector or concentrated type solar collector.

The heating process is either passive or active. This hot air then flow in the cabin where products are stored. Therefore moisture from the product may lost by convection and diffusion. This method of drying is used to avoid direct exposing to the solar radiation. This method mainly reduces the disadvantages of direct solar drying. In mixed mode solar dryer, the combined action of the solar incident radiation on the material to be dried and the heated air in solar collector provide the required heat for the drying operation. [3] It is combination of direct and indirect solar drying method. Product may dry with both direct exposure to solar radiation and hot air supplier on it. Air may heated in solar energy collector first then pass to the chamber where products are stored. In this process product may dry according to convective moisture loss. The same chamber is partially or totally covered with the transparent material to exposure the products to solar radiation as shown in Fig.4. System is divided into three main components: an air-heater,
drying chamber, and a chimney. Air-heater through which the drying air is heated as it flows over and under an absorber plate that is heated in turn by direct absorption of incident radiation. Crop to be dried is placed in drying chamber. The moist air flows through chimney and escapes into the surrounding. Solar energy is incident on the planes of the primary collector and the drying chamber. [3]

### TABLE I: Specification of Constructed Mixed Mode Solar Dryer

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mode of heating</td>
<td>Mixed mode type</td>
</tr>
<tr>
<td>2</td>
<td>No. of tray</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Cover material</td>
<td>Acrylic</td>
</tr>
<tr>
<td>4</td>
<td>Air circulation mode</td>
<td>Natural convection</td>
</tr>
<tr>
<td>5</td>
<td>Thickness of acrylic</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>6</td>
<td>Slope of collector</td>
<td>20 degree</td>
</tr>
</tbody>
</table>

Fig.1. Direct Type of Solar Dryer [4].

Fig.2. Indirect Type Solar Dryer [4].

Fig.3. Mixed Mode Type Solar Dryer [4].

Fig.4. Experiment Photo.

### II. DRYING TECHNOLOGY

Solar drying is a very important application of solar energy. The purpose of drying an agricultural product is to reduce its moisture content to a level that prevents its deterioration. Drying is usually conducted by vaporizing water in the product. Airflow is also required to remove the vapor away from the product. As the less humidity air can carry more moisture from the product surface than the more humidity air, drying rate is better. In comparison to natural sun drying, solar dryers generate higher temperature and lower relative humidity.

#### A. Operation of Mixed Mode Solar Dryer

The incident solar radiation passes through the transparent cover and reaches the absorber plate (Aluminium) in the flat plate collector. Inlet air enters into the flat plate collector and is transferred heat by convection. The heated air flows towards the drying chamber and then passes through the drying trays. There are two trays in this drying chamber. At the same time, the drying chamber absorbs solar energy that it directly passes through the transparent walls and top cover. The heated air from the flat plate collector is mixed with direct solar energy. And then, the heated air containing moisture content leaves through the chimney (air outlet).
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III. METHODOLOGY

A. Total Solar Insolation

Total solar radiation coming from the sun to the earth surface can be used for generating electricity for heating of water, air and other materials. The global solar radiation incident on a collector surface is usually in the form of beam (direct), diffuse (sky) and solar radiation reflected from the ground and the surroundings.

\[ I = I_a \cos \theta + I_d \frac{(1+\cos \beta)}{2} + I_g \rho_{\text{ground}} \frac{(1-\cos \beta)}{2} \]  

(1)

The direct or beam solar flux striking a surface is denoted by \( I_b \). The direct solar radiation is that received from the sun without have been scattered by the atmosphere. \[ I_b = I_{0,\text{eff}} \left[ a_0 + a_\epsilon \exp \left( -\frac{k}{\cos \theta_x} \right) \right] \]  

(2)

The diffuse solar radiation is that received from the sun after its direction has been changed by scattering by the atmosphere. The diffuse solar flux striking a surface is denoted by \( I_d \).

\[ I_d = [0.2710 I_{0,\text{eff}} - 0.2939 I_b] \cos \theta_x \]  

(3)

The hemispherical radiation can be calculated by using eq. 4.

\[ I_h = I_b \cos \theta_x + I_d \]  

(4)

B. Total Energy Gain in Drying Chamber

Total energy gain is the combination of the energy gain from top, front, side and collector.

\[ Q_{\text{Tg}} = Q_{\text{gt}} + Q_{\text{gf}} + Q_{\text{gs}} \times 2 + Q_{\text{coll}} \]  

(5)

Energy gain from cover depends on absorptance of transparent cover, area of cover and total solar insolation.

\[ Q_{\text{gt}} = \alpha A_t I \]  

(6)

\[ Q_{\text{gf}} = \alpha A_f I \]  

(7)

\[ Q_{\text{gs}} = \alpha A_s I \]  

(8)

C. Total Energy Loss from Drying Chamber

Total energy loss is the loss from drying chamber to the environment by various conditions.

\[ Q_{\text{loss}} = Q_{\text{fc}} + Q_{\text{fc}} + Q_{\text{tc}} \times 2 + Q_{\text{bot}} + Q_{\text{amit}} + Q_{\text{ref}} \]  

(9)

Energy loss from cover depends on the temperature difference between cover and ambient.

\[ Q_{\text{fc}} = \Delta T \sum R_{\text{f}} \frac{(T_{\text{fc}} - T_{\text{am}})}{h_{\text{fc}} A_{\text{fc}} + \frac{x}{k A_{\text{tc}}}} \]  

(10)

D. Energy Loss from Air Outlet

After the inlet air enters from the collector and leaves from the air outlet. In this time, it carries with energy from drying chamber.

\[ Q_{\text{amit}} = m^o \times C_p \times \Delta T \]  

(16)

\[ m^o = \rho A_o V_o \]  

(17)

E. Energy Loss by Reflection from Drying Chamber

Reflection from drying chamber is considered for energy loss. It can be calculated by eq.16.

\[ Q_{\text{ref}} = h_{\text{tc}} A_{\text{tc}} (T_{\text{tc}} - T_{\text{am}}) \]  

(18)

The radiative heat transfer coefficient is derived using the following equations.

\[ h_{\text{tc}} = \frac{\varepsilon \sigma (T_{\text{tc}} + T_s) (T_{\text{tc}}^2 + T_s^2)}{0.8 + \frac{(T_{\text{dp}} - 273)}{250}} \]  

(19)

F. Useful Energy

Useful energy in drying chamber is the difference between total energy gain and total energy loss.

\[ Q_u = Q_{\text{Tg}} - Q_{\text{loss}} \]  

(21)

G. Drying Chamber Efficiency

The drying chamber efficiency is defined as the ratio of
useful energy and total energy gain.

$$\eta = \frac{Q_u}{Q_{Tg}} \times 100\%$$  \hspace{1cm} (22)

H. Moisture Content

Moisture content can be determined by the following equation,

$$M.C = \frac{W_f - W_i}{W_i} \times 100\%$$  \hspace{1cm} (23)

TABLE II: Design Specification

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location</td>
<td>Mandalay, Myanmar (Long 96.7°E, Lat 21.98°N)</td>
</tr>
<tr>
<td>2</td>
<td>Drying time</td>
<td>May</td>
</tr>
<tr>
<td>3</td>
<td>Food products</td>
<td>Mango and Potato</td>
</tr>
<tr>
<td>4</td>
<td>Drying capacity for tray 1 (mango)</td>
<td>813.4 g/tray</td>
</tr>
<tr>
<td>5</td>
<td>Drying capacity for tray 2 (mango)</td>
<td>911 g/tray</td>
</tr>
<tr>
<td>6</td>
<td>Drying capacity for tray 1 (potato)</td>
<td>646.8 g/tray</td>
</tr>
<tr>
<td>7</td>
<td>Drying capacity for tray 2 (potato)</td>
<td>601.6 g/tray</td>
</tr>
<tr>
<td>8</td>
<td>Thickness of mango</td>
<td>3 mm</td>
</tr>
<tr>
<td>9</td>
<td>Thickness of potato</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

IV. RESULTS AND DISCUSSION

A. Solar Insolation Flux

Fig.5. Solar Insolation Flux by monthly.

In Fig.5 shows total solar insolation flux by hourly rate in drying chamber. Experiment tested in May, 2014. In this Figure, solar insolation flux is gradually increased from 9:30 to 11:30 about 893 W/m² and then it is steady decrease from 11:30 to 3:30.

B. Total Energy Gain

Fig.6. Total Energy Gain in Drying Chamber.

In Fig.6, express total energy gain in May, 2014 in drying chamber. In this figure, total energy gain is maximum at 11:30 nearly 540 W due to solar insolation is maximum in that time.

C. Total Energy Loss

Fig.7. Total Energy Loss in Drying Chamber.

In Fig.7, shows total energy loss in May, 2014 in drying chamber. Total energy losses occur due to temperature changes and environment effect during drying process.

C. Useful Energy in Drying Chamber

In Fig.8, explain useful energy in drying chamber. In this figure, useful energy is maximum at 12:30 about 387 W. I think, at that time less received temperature difference.
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D. Efficiency for Drying Chamber

In Fig. 9, express efficiency in drying chamber. In this Figure, efficiency is maximum at 12:30 because useful energy are maximum in this time.

E. Moisture Content

In Figs. 10 and 11, express moisture content for mango and potato in mixed mode solar dryer.

V. CONCLUSION

A mixed mode solar dryer is designed and constructed with natural convection using wood, plywood, acrylic and aluminium from local market. Experimental results are performed in May. Solar insolation flux, total energy received, total energy loss, useful energy and efficiency are calculated. The drying chamber efficiency is 73% in May. The drying capacity used in drying chamber is for first tray 813.4 g/tray and for second tray 911 g/tray. The system can remove mango’s moisture content for first tray 72% (w.b) to 8% (w.b) and for second tray 72% (w.b) to 13% (w.b) and can reduce for potato’s moisture content 81% (w.b) to 5% (w.b) for each tray. Moreover, in my idea that transparent cover should be used glass. It has more transmittance than acrylic. If the more transmittance, solar energy more receive. So, system efficiency is better.

VI. ACKNOWLEDGMENT

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VII. NOMENCLATURE

$I_{b}$  beam radiation, W/m$^2$
\(\theta\)  incidence angle, degree
$I_{d}$  diffuse radiation, W/m$^2$
\(\beta\)  slope of collector, degree
$I_{h}$  hemispherical radiation, W/m$^2$
\(\rho_{\text{ground}}\)  relativity of the ground in front of the collector
$I_{0,\text{eff}}$  effective solar constant
$I_{0}$  the solar constant, 1373 W/m$^2$
n  no of days
\(a_0, a_1, a_2\)  correction factors for climate type
\(\theta_z\)  solar zenith angle, degree
H  elevation, m
\(Q_{eg}\)  energy gain by top cover, W
\(Q_{ef}\)  energy gain by front cover, W
\(Q_{es}\)  energy gain by side cover, W
\(A_t\)  top cover area, m$^2$
\(A_f\)  front cover area, m$^2$
\(A_s\)  side cover area, m$^2$
\(Q_{et}\)  energy loss from top cover, W
\(Q_{ec}\)  energy loss from front cover, W
\(Q_{es}\)  energy loss from side cover, W
\(Q_{bot}\)  energy loss from bottom cover, W
\(Q_{bot}(\text{cond})\)  energy loss from potato by conduction, W
\(Q_{bot}(\text{conv})\)  energy loss from potato by convection, W
\(Q_{a}\)  energy loss from air outlet, W
\(Q_{ref}\)  energy loss by reflection from drying chamber, W
\(m^*\)  air mass flow rate, kg/s
\(\rho_a\)  density of air, kg/m$^3$
\(A_o\)  air outlet area, m$^2$
\(V_o\)  air velocity at outlet, m/s
\(C_p\)  specific heat capacity, kJ/kg K$^*$
\(\Delta T\)  temperature difference between drying chamber and air outlet, K$^*$
\(h_c\)  radiative heat transfer coefficient, W/m$^2$ K
\(A_T\)  total area of drying chamber, m$^2$
T$\text{am}$  ambient air temperature, K
\(\varepsilon_{\text{cl}}\)  emittance of acrylic
T$\text{ck}$  top cover temperature, K
\(\sigma\)  Stefan-Boltzmann constant
T$\text{s}$  sky temperature, K
T$\text{dwp}$  dwe point temperature, K
k$\text{pot}$  thermal conductivity of potato, W/m.K
\(A_{pot}\)  potato area, m$^2$
\(l_{pot}\)  length of potato, m
T$\text{pot}$  potato temperature, K
h$\text{pot}$  heat transfer coefficient from potato, W/m$^2$.K
W$\text{i}$  initial weight for product, g
W$\text{f}$  final weight for product, g

VIII. REFERENCES

Performance Of Solar Dryer Chamber Used For Convective Drying Of Sponge-Cotton", Mechanical Power

Department, High Institute of Energy, South Valley University, Aswan, Egypt.