An Experimental Investigation of the Fruit Drying Performance of a Heat Pump Dryer

Adonis A. Closas, and Prof. Eliseo P. Villanueva, Ph.D.

Abstract—A heat pump dryer was designed, fabricated and tested. Its main feature is its capability to adjust the drying air moisture content and temperature depending on the drying requirements of a particular fruit. Mango, a well-known fruit in the Philippines with its widely popular dried mango product was dried and the product was tested and verified as to its nutrient values and physical appearance. The total weight of 818.16g of fresh mango was loaded in the drying chamber. The mango sample has an initial moisture content of 63.6% was dried to 15% wet basis. The drying air enter the dryer at 50 °C dry bulb temperature and 18.5% average relative humidity with a mass flow rate of 0.047 kg/s and drying air velocity of 0.7m/s. Moisture loss was determined using digital weighing balance through changed in the weight of slice mango during the drying process. The result shows that 584.88g of water was evaporated and 4.8 kWh of energy was consumed. The heat pump dryer system specific moisture evaporation rate (SMER) was 0.122 kg/kWh. The vitamin C content before drying was 1.5mg/100g and after drying was 2.2 mg/100g. The drying process time to reach the final moisture content was 6.25 hours. It was found out that vitamin C content was not degraded. The developed dryer is suitable in drying heat sensitive product.

Keywords—Heat Pump Dryer, Mango, Specific Moisture Evaporation Rate, Vitamin C.

I. INTRODUCTION

Drying is one of the oldest methods of preserving food. It is a process in which moisture is removed from a solid using heat as the energy input. Drying is a common unit operation in food processing facilities to lower the moisture content of foods in order to reduce water activity and prevent spoilage or the weight and the volume of food products for transport and storage. In many agricultural countries large quantities of food products are dried to improve shelf life, reduce packaging costs, lower shipping weights, enhance appearance, retain original flavor and maintain nutritional value [1].

Drying is a complex operation involving combined heat and mass transfer. It is an energy intensive process. Product quality could be degraded during drying operation. Foods like fruits and vegetables are especially high in carbohydrate, vitamins and water. These compounds are easily altered in high temperature drying condition and result in food quality degradation [1]. Thus to increase the benefit of the dried product production, an energy efficient dryer with better product quality should be applied for food drying.

In the conventional hot air dryer, air is heated up to the drying temperature using electrical heaters. Agricultural products are dried by using conventional hot air dryers. However, the conventional method uses high drying air temperature causing low product quality. In addition, the humid air leaving in the drying chamber is expelled to the ambient air, which result in the loss of both sensible and latent heat of the humid air. The relative humidity of the process air is dependent on the ambient conditions. The use of a heat pump dehumidifier dryer enables control over the moisture content and the temperature of the process air as well as the recovery of the latent heat of vaporization of water from the exhaust stream that is otherwise lost as waste heat. Moreover, the ability of the heat pump to convert the latent heat of vapor condensation at the evaporator coil, and delivers the recovered energy as sensible heat to the drying air stream passing through the condenser coil makes them attractive.

Reference [2] reviews state that heat pump dryer has higher drying efficiency, offers better product quality, and it is environmentally friendly. SMER values ranged from 1.0 – 4.0, 0.7 – 1.2 and 0.1 – 1.3 kg/kWh for heat pump dryer, vacuum drying and hot air drying respectively. Drying efficiencies were 95% for heat pump dryer, less than 70% for vacuum drying, and between 35% – 40% for hot air drying.

Reference [3] studied the performance of a heat pump dryer system for specialty crops. In this study experimental and predicted performance data were reported. Chopped alfalfa was dried in a cabinet dryer in batches and also by emulating continuous bed drying using two heat pump operating in parallel. Results showed that alfalfa was dried from an initial moisture content of 70% (wb) to a final moisture content of 10% (wb). The batch drying took about 4.5 hours while continuous bed drying took 4 hours to dry the same amount of material. Low temperatures (30 – 45 °C ) for safe drying of specialty crops were achieved experimentally. Specific moisture extraction rate (SMER) was maximum when relative humidity stayed above 40%. The dryer was shown to be capable of SMER of between 0.5 and 1.02 kg/kWh.

Reference [4] developed and evaluated the performance of a batch type heat pump assisted dehumidified air dryer. Medium range of temperatures (30 – 41 °C) for safe drying of sweet pepper were achieved. Dehumidification system of the developed heat pump dryer maintained the relative humidity of air entering the drying chamber below 40%. Result showed have a specific moisture extraction rate (SMER) between 0.55 and 1.10 kg/kWh. Energy consumption for 24 hours of operation was found less (4.48 – 5.05 kWh) than the hot air

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The objective of this study is to investigate experimentally the fruit drying performance of a developed, fabricated laboratory scale heat pump dehumidifier dryer prototype, determine the energy consumption and the quality of the dried product.
C. Experimental Procedure

The drying experiment was performed at 50 °C. A total weight of 818.16 g of sliced mango was prepared and 88.16 g was taken as a test sample and then was loaded to the drying chamber. The average thickness of the sample was about 13 mm measured using vernier caliper. The test sample was placed in a plastic tray. The weights of plastic tray and the test sample were measured using a high precision balance. The mango sample has an initial moisture content of 66.5% wet basis. The drying air enter the drying chamber at 50 °C dry bulb temperature and 18.5% average relative humidity with a mass flow rate of 0.047 kg/s and drying air velocity of 0.7 m/s. Moisture loss was determined through weighing the test sample during the experimentation, the tray with the test sample was taken out from the drying chamber, weighed on the digital balance and recorded every 15 minutes interval for all temperatures selected for the study and placed it back into the drying chamber immediately after the weighing. The drying procedure was repeated and the drying experiment was stopped when the calculated final moisture content of the dried sample reached 15% wet basis.

D. Moisture Content

The equation for calculating moisture content on any drying material based on wet basis (w.b.) is given by:

\[ \% \text{ moisture content (w.b.), } X^* = \frac{\text{mass of moisture}}{\text{total mass of moist material}} \]

\[ \% \text{ moisture content (w.b.), } X^* = \frac{m_m}{m} = \frac{m - m_{bd}}{m} \times 100 \]  
(1)

where \( m_m \) is the mass of moisture (kg), \( m_{bd} \) is bone dry mass (kg) and \( m \) is the total mass of moist material (kg).

And for moisture content on dry basis (d.b.) is by:

\[ \% \text{ moisture content (d.b.), } X = \frac{\text{mass of moisture}}{\text{bone dry mass}} \]

\[ \% \text{ moisture content (d.b.), } X = \frac{m_m}{m_{bd}} = \frac{m - m_{bd}}{m_{bd}} \times 100 \]  
(2)

Calculating the moisture that would be lost during drying from an initial moisture content, \( X_i \) to a final moisture content \( X_f \) can be formulated as follows. Initial mass of a drying material, \( m \), can be denoted \( m_i \) and it consists of the initial mass of moisture, \( m_{mi} \) and bone dry mass, \( m_{bd} \). That is

\[ m_i = m_{mi} + m_{bd} \quad X_i = \frac{m_{mi}}{m_{bd}} \quad \text{and} \quad m_{mi} = X_i m_{bd} \]  
(3)

Therefore

\[ m_f = m_{bd} (1 + X_f) \]  
(5)

The moisture loss during drying can be written as:

\[ m_i - m_f = m_{bd} (1 + X_f) - m_{bd} (1 + X_f) = m_{bd} (X_i - X_f) \]  
(6)

E. Specific Moisture Evaporation Rate (SMER)

A performance indicator that is widely used to define the performance of Heat Pump Dryer (HPD) system was the specific moisture evaporation rate (SMER). SMER was defined as:

\[ \text{SMER} = \frac{\text{Amount of moisture evaporated (kg)}}{\text{Energy input to the dryer system (kWh)}} \]  
(7)

F. Vitamin C Analysis

Vitamin C determination was performed using Icdometric Titration method using Buret apparatus (accuracy ± 0.01). Vitamin C value was expressed in mg / 100 g sample. The analysis was done at the Analytical Laboratory Services Center, Department of Chemistry, Mindanao University of Science and Technology, Philippines.

III. RESULTS AND DISCUSSION

A total weight of 818.16 g of fresh mango was loaded in the drying chamber, 88.16 g was taken out from the 818.16 g of fresh mango and was used as a test sample. The mango sample has an initial moisture content of 66.5% (wet basis) was dried in a developed and fabricated heat pump dehumidifier dryer incorporating and external condenser down to a final moisture content of 15% (wet basis). The drying air enter the drying chamber at 50 °C dry bulb temperature and 18.5% average relative humidity with a mass flow rate of 0.047 kg/s and drying air velocity of 0.7 m/s.

A. Calculation of Specific Moisture Evaporation Rate

The reduction of the moisture or water content of the sample was shown in Fig. 2. It shows the variation of the moisture content of mango sample with time. The total drying time to this process to reach the final moisture content was about 6.25 hours. The recorded dryer system total energy consumed from the start of drying to the end was 4.8 kWh. The total amount of moisture loss or water evaporated from the sample was calculated using (6) and the value was about 584.88 g. It shows that from using (7), the calculated heat pump dehumidifier dryer system specific moisture evaporation rate (SMER) was 0.122 kg/kWh.
It was observed that to increase the value of SMER more water should be removed during the drying process that is increasing the material mass flow rate through the dryer and at the same time relatively increased the relative humidity of the process air. The SMER increases with an increase in humidity in the dryer [8].

B. Analysis of Vitamin C Content

In the experiment conducted at 50 °C dry bulb drying air temperature vitamin C was analyzed from a fresh mango sample has an initial moisture content (wet basis) of 66.5%, w.b., the initial vitamin C content value before drying was 1.5mg/100g. And after drying the vitamin C content was 2.2mg/100g. A total of 584.88 g of water was evaporated or removed. The result shows that there was an increased in the vitamin C content or better retention of ascorbic acid. As much water has been removed from the material this helps to conserve ascorbic acid and it becomes concentrated. In Fig. 3 shown below, it shows the drying air temperature over the drying time. In Fig. 3 at the onset of drying the drying air has low initial temperature followed by an elevated drying air temperature as drying proceeds. And in Fig. 2 drying starts at higher product moisture content and it decreases as drying progresses. These drying characteristics yield a better product quality as shown in the result of vitamin C analysis. Ascorbic acid is sensitive to high temperature at high moisture contents. Ascorbic acid retention of the product can be optimized. The product should be dried at a low initial temperature when the moisture content is high since ascorbic acid is most heat-sensitive at high moisture contents. The temperature can then be increased as drying progresses and ascorbic acid is more stable due to a decrease in moisture [9] - [10].

IV. CONCLUSION

An experimental work in the investigation of the fruit (mango) drying performance of a heat pump dryer had led to the following conclusions:

1. Drying temperature of 50°C for safe drying of high value and heat sensitive product was achieved experimentally.
2. About 584.88 g of moisture or water removed (evaporated) in the dryer. A total of 4.8 kWh of energy consumed for about 6.25 hours duration of drying process.
3. The dryer was shown to have an effectiveness of energy used in the drying process, the specific moisture evaporation (extraction) rate SMER was 0.122 kg/kWh.
4. The value of vitamin C content of both fresh (before drying) and HPD-dried mango were 1.5mg/100g and 2.2mg/100g respectively.

It was concluded that vitamin C content was not degraded. The developed dryer was suitable in drying high value and heat-sensitive products and it capable to adjust drying conditions and better ascorbic acid retention.

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