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Use of heat pump dehumidifiers on industrial drying of chili

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Abstract- Chili, a potential cash crop in the world is considered as one of the most important spices due to its multiple uses and vital role in most of the cuisines. Traditional drying systems use direct sunlight or indirect heating sources and hence difficult to control the drying conditions. Convective drying systems use hot air and because of high temperature, volatile compounds tend to remove from the product leading to a quality reduction. Use of dehumidified air for drying has been suggested as one of the solutions as drying can be done at relatively lower temperatures while preserving the volatile compounds. In this study, a heat pump drying (HPD) system was designed, evaluated and then validated to be used as an alternate method of drying chili in the industry level. Weight and the bulk density of the evaluated sample were 8,000 kg and 98 kg/m^3 respectively. The Specific Moisture Removal Rate (SMER) value of the evaluated HPD system was 1.027 kg/kWh. The moisture content of chili was reduced from 10.8% to 5.05% (wet basis) within three hours. The relative humidity of the dehumidified room was reduced to 8% from 55% and the temperature of the dehumidified room increased from 29°C to 41°C within three hours. Average water condensed rate was 5.2kg/h. Results suggested that the developed heat pump drying system has performed well serving its purpose and hence it can be concluded that the established closed cycle heat pump drying system can be effectively used to dry chili in industrial level.

Index Terms- Heat pump drying, Specific Moisture Removal Rate, Dehumidified air, Food preservation.

I. Introduction

Chili is an important spice and a potential cash crop in the world and used as a basic ingredient in most of the cuisine all over the world and more especially in South Asian countries like Sri Lanka. Chili is consumed in both fresh and dry forms and the per capita consumption and the national annual requirement of dry chili are estimated in Sri Lanka as 2.32 kg per annum and 42,634 metric ton respectively (Amaratunga & Fernando, 2014). Chili is dried for making chili powder for both short and long-term storage (Hossain et al., 2005). Due to the lack of postharvest processing facilities, considerable amount of produce is wasted. Therefore, identifying proper methods for preserving chili is in need over the time along with the concept of food security.

Drying is one of the most widely used methods of preserving foods and more especially chili around the world in both domestic and industrial level. The preservation in drying is due to the removal of water from the food preventing the growth of microorganisms (Gupta, et al., 2002). Traditional drying is done by direct sunlight or using indirect heat sources but it is difficult to control the drying conditions and highly dependent on weather. Hot air is used in convective drying systems however due to high temperature, flavor compounds tend to volatilize leading poor quality of spices. Well-developed conventional drying methods are widespread in the food industry and such methods are exemplified by heat pump system. Heat pump drying (HPD) is a rapidly emerging technology, which can be used to dry spices within a controllable drying environment, specifically the temperature and humidity.

Heat pumps transfer heat from a source of heat to a destination called a "heat sink" and one of the important factors to be noted here is that it uses comparatively a small amount of external power to accomplish this task. Heat pumps have been designed in such a way that the thermal energy moves in the opposite direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer one.

Maintaining and controlling the correct levels of moisture content throughout the processing is the key factor in achieving the expected quality and it can be achieved using HPD system as it uses dehumidified air for drying at relatively low temperature while preserving the volatile compounds. In addition, environmental concerns are minimal and economic viability is in an acceptable range. It is therefore HPD can be considered as an alternative method for drying chili owing to its specific characters. However designing and evaluating of HPD system in the Chili processing industry is yet not well developed and it is therefore the study was conducted with the main objective of evaluating the compatibility of HPD system for mass drying of chili to be used in industry by analyzing the specific moisture extraction rate (SMER).

II. METHODOLOGY

The fundamental principle in the process of drying in the developed HPD system involves creating a moisture gradient between material and the surrounding air by removing the moisture in the air. In order to facilitate this process the chili dehumidifying system was designed with three main components namely i) an evaporator; to condense moisture in the air, ii) an industrial blower; to facilitate air circulation and, iii) a container fabricated with a capacity of 8,000kg; to hold chili. Air circulation facilitate the movement of high RH/ low-temperature air to the dehumidifier and taking away low RH/ heated air. As the drying percentage depends on moisture content (humidity) of the air and temperature a special attention has been given for maintaining required airflow rate in order to keep the relative humidity and temperature at the required level. The top and front views of the dehumidifying system are illustrated in the figures 1 and 2.

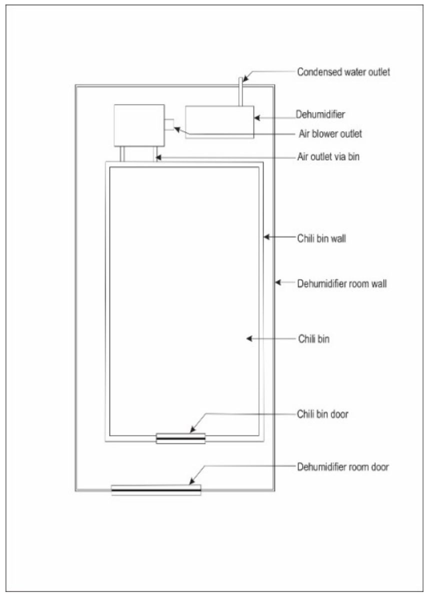

Figure 1: Top view of the dehumidifying system

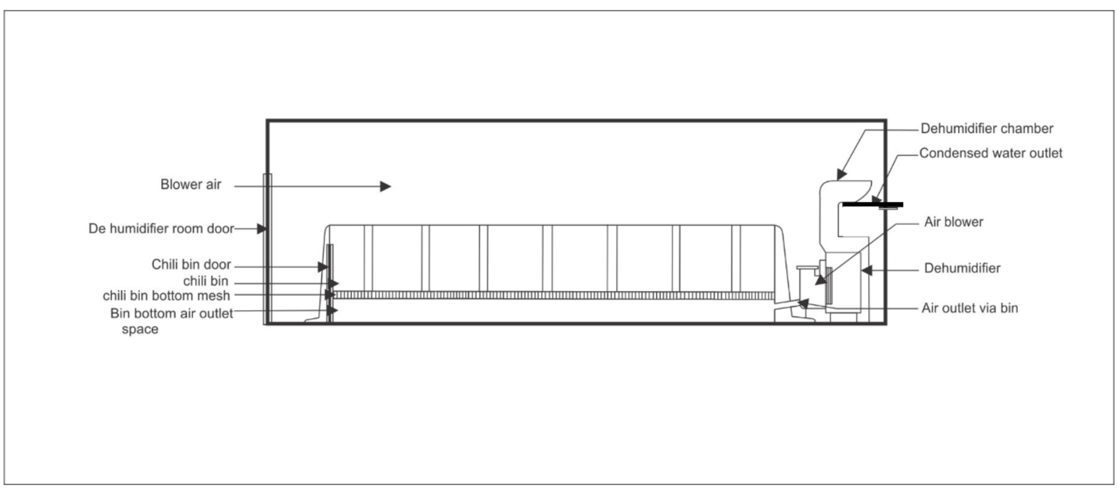

Figure 2: Front view of the dehumidifying system

Chili holding container

Dimensions of the designed metal container were 10 ×2.50 ×1.20 m. The bottom was sealed and covered with a wire mesh to facilitate the air movement. The gap between wire mesh and the floor was 0.25m. Air flow movement through the container is illustrated in Figure 3.

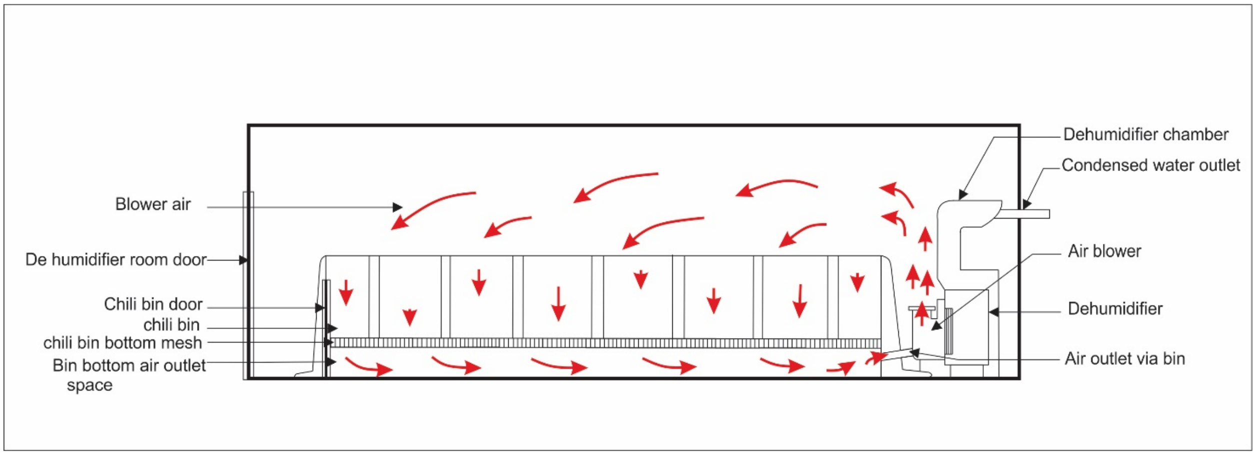

Figure 3: Air flow movement through the container

Air circulation in the dehumidified room was facilitated by using a centrifugal industrial blower. Air was sucked by the blower from the bottom of the chili container and push that air toward the evaporator. The air flow rate of the centrifugal industrial blower is 0.14 ms^{-1}. Dehumidify system was absorbed air coming from the blower, which has high moisture content and low temperature. Same time it was released heated air with low RH. Throughout the process, blower was switched on to facilitate air movement from top to bottom of the chili container. The blower was attached to a three-phase motor, which has 1600 rpm. Current usage for the motor was measured using a clip-on ammeter (HTC Instrument CM-2030 Digital Ac Clamp Meter).

Heat pump was used to reduce the relative humidity of air with elevated temperatures to facilitate the drying process. The working mechanism of dehumidifier is illustrated in the Figure 4. Evaporator in the dehumidifier receives cold air, which contains high RH from the blower, and then the moisture in the cold air condenses at the evaporator while passing through. As a result of that cold air with low RH comes out from the evaporator. Then the cold air is directed into the condenser. Cold air gradually increases its temperature while passing through the condenser and the relative humidity of air decreases.

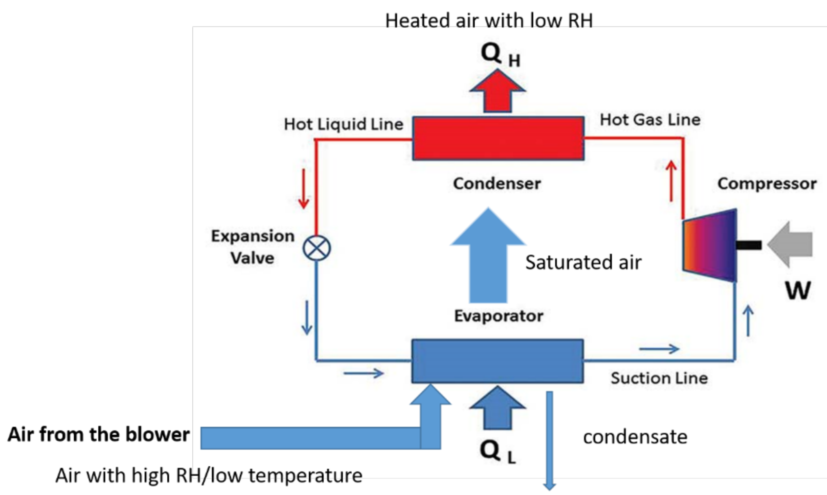

Figure 4: Air flow movement from the blower to dehumidifier

Dehumidify machine and blower were attached to the floor to avoid the vibrations. The temperature and relative humidity inside the dehumidified room were measured and recorded using an Arduino circuit (Genuino Uno Rev3) and a RH and temperature sensor (DHT11 Module) unit. The current and voltage consumed by the dehumidifier and the industrial blower was measured using clip-on meter (HTC Instrument CM-2030 Digital Ac Clamp Meter). Air flow rate was measured using a portable hot wire anemometer (XINTEST, HT-9829).

The energy consumption of the heat pump drying system was calculated using equation 1, 2, and converted to kilo Watt hour using equation 3.

$$p = \sqrt{3}\, UIcos\, \emptyset \qquad (1)$$

P = power (W, Js^{-1}), U = line-to-line voltage (V), I = current (A), $\cos \emptyset$ = power factor (0.86)

$$E = pt \quad (2)$$

E = Energy (J), t = time (s)

$$Energy = \frac{E}{3.6*10^6} \quad (3)$$

Condensed water from the dehumidifier was collected and measured one hour time intervals while system working. The specific moisture removal rate (SMER) was calculated using equation 4.

$$SMER = \frac{Amount\ of\ water\ evaporated}{Energy\ input\ to\ the\ dryer} \quad (4)$$

III. RESULTS AND DISCUSSION

The duty cycle of the HPD system is one hour on time and 10 minutes off time. Current usage of the HPD system shown in Table 1. Evaporated water from the dehumidifier was recorded with the time Table 2. Relative humidity and temperature variation inside the dryer was recorded with the time.

Table 1: The current usage of HPD system

Time (min)	Status of the machine	Current (A)	Voltage (V)
60	on	8.5	400V
10	off	0	400V

Table 2: Amount of condensed water by HPD system with time

Time interval (min)	Condensed Water (ml)
60	5600
60	5200
60	4800

Initial moisture content of the chili was 10.80 % wet basis. Moisture content was measured using an infrared moisture meter (Sartours, MA45) in the top layer of the chili container and the middle of the container. Moisture content was recorded with the time (table 3).

Table 3: Moisture content variation with time

Time (hours)	Chili moisture content (wet basis) Top layer of the container	Chili moisture content (wet basis) Middle of the container
1	6.09	9.31
2	5.93	7.23
3	5.05	7.17

Average water condensed rate was 5.2kg/h. Following data were obtained using equation 1 and 2,

$$p = 5.064kW$$

$$E = 18.23MJ$$

Power consumption per hour was 5.064 kW/h calculated using equation 3. Specific moisture extraction rate was 1.027 kg/kWh calculated using equation 4.

The Specific Moisture Removal Rate (SMER) value indicates the performances of the dryer. It is expressed as the ratio of the amount of water evaporated to energy input to the dryer. In-other-words it is the amount of energy required for to remove 1kg mass of water from the food material. Normally SMER values in heat pumps vary between 1.0 – 4.0 (Rahman, *et al.*, 1998).

Initially, there was around 48% RH in the room, but with the operation of the dehumidifier, the RH reduced to 8% after three hours as shown in Figure 5. The temperature of the dehumidifying room was 29 Celsius and with time, it increased to 41 Celsius as shown in Figure 6. The temperature in the dehumidified room did not exceed 41 Celsius and it is important to maintain the quality of the product. Otherwise, oregano sulphur compounds and volatile fatty acids will be evaporated at higher temperatures.

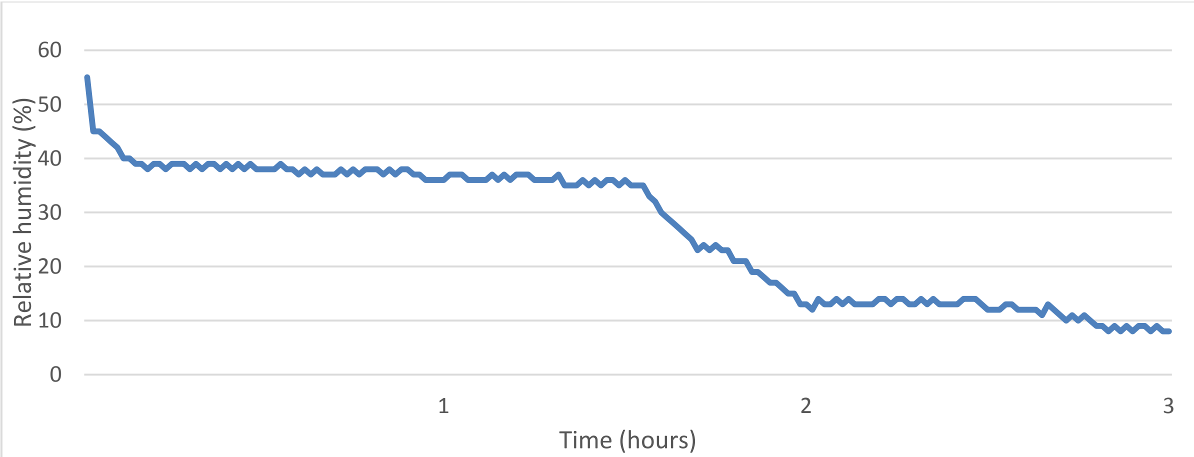

Figure 5: Relative humidity variation vs time

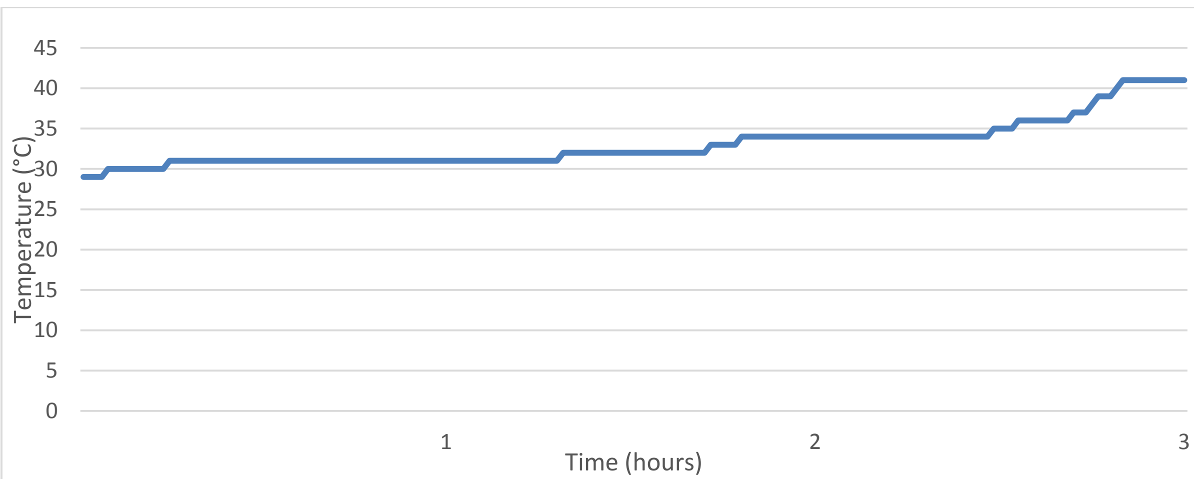

Figure 6: Temperature variation vs time

IV. CONCLUSION

The developed heat pump drying system performed well with chili. SMER for the heat pump drying system was 1.027 kg/kWh. The moisture content of the chili at the top layer was reduced from 10.8 % (wet basis) to 5.05 % (wet basis) within three hours. Relative humidity of the dehumidified room reduced from 55% to 8% within three hours. The temperature of the dehumidified room increased from 29°C to 41°C within three hours. Therefore, it can be concluded that the established closed cycle heat pump drying system could be effectively used in drying chili in industrial scale.

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