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Research Article

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Design and Development of a Closed Cycle Heat Pump Drying System for Industrial Drying of Rice and Chili

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Abstract A closed cycle heat pump drying system was developed to study the thin layer and deep bed heat pump drying characteristics of rice and chiliin industrial scale. Two units of dehumidifiers assembled with heat pumps with a capacity of 0.95 kW were placed in a modified air-tight room (10 m x 3 m x 3 m) for dehumidifying air. The commodities to dry were tested inside this dehumidified room for the drying rate variations and the efficiency of the system. A microprocessor-based primary control system was used to vary the duty cycle of dehumidifiers and thereby control the operational behavior of the dehumidifiers. The secondary control system was used in controlling the relative humidity in the dehumidified room by using RH sensor and a microprocessor-based control system. The variation of moisture content of rice and chili was observed in thin layer and deep bed drying in the dehumidified room. After 65 minutes of operation, the relative humidity and temperature of the empty store room reached 16% and30^{0}C simultaneously. The calculated MER value for heat pump drying system was 1.2 kg-water/h. The SMER for rice and chili was 0.7 kg-water/kWh and 1.4 kg-water/kWh respectively. The optimum final moisture content of rice and chili could be achieved by rice and chili. Thin layer heat pump drying rates were higher than the deep bed heat pump drying of rice due to the higher air circulation through thin layers of rice. Chili had similar thin layer and deep bed heat pump drying rates because of the low density and high porosity of chili layers. In conclusion, thin layer and deep bed heat pump drying technology could be applied to achieve the optimum moisture content for rice and chili respectively in industrial scale. Further studies are required to optimize the performance of the heat pump drying system.

Keywords chili, drying, heat pump, rice

Introduction

Drying process removes moisture from the food inhibiting the growth of bacteria, yeast, and mold. Economic considerations, environmental concerns, and product quality aspects need to be enhanced in drying processes [1]. Direct heat drying methods are used to reduce the moisture of low moist product, yet is less efficient and requires high heat energy [2-3]. Drying incorporated with dehumidification cycles are called heat pumps dryers. By using heat pump drying (HPD), material can be dried at low temperature and in an oxygen free atmosphere using energy. The recovered waste heat is recycled back to the dryer at high temperature for reuse in the drying process. This helps to improve the energy efficiency and reduces primary energy consumption. This method is more advantageous for drying biological materials than common methods which are thermal and oxygen sensitive [4-5].

Production of rice flour and powdered chili is major agricultural processing in Sri Lanka due to high market demand within the country. Maintaining and controlling correct level of moisture content throughout the processing chain of both rice and chili is the key factor which is directly affect the quality of product. Paddy drying, hulling, milling, storing and grinding are main postharvest handling processes which directly affect the quality of rice and rice flour. Raw rice is used to produce rice flour and maintaining correct amount of moisture level is the governing factor for milling quality in rice flour production [6]. Rice is dried within a fairly short period after harvest to 12%-13% moisture before being placed in storage. Under ambient storage, raw rice moisture content goes up to 16% and that high moisture content leads to fissure and, increased temperature cause growth of mold and insects and agglomeration, reduce milling percentage in flour production. Therefore, moisture content should be reduced up to 10% to ensure proper milling and high-quality flour [7-9].

Chili is used as a basic ingredient in most of the cuisine all over the world. Per capita consumption of chili in the form of dry chili is estimated 2.32 kg per annum and the national annual requirement of dry chili is around 42,634 MT in 2007. The quality of chili powder is greatly affected by the postharvest operations and storage. Chili is hygroscopic and its' moisture content fluctuate during storage. Ambient stored chili absorbs moisture and increase temperature leading unsaturated solid fats convert to liquid fats forming a leathery texture which reduces the milling percentage. Therefore, proper storage condition is required for production of high-quality powdered chili [10]. Further, high drying temperatures lead to loss of volatile compounds which directly affect to quality of chili powder.

Moisture content of rice needs to be reduced to 11% (w.b.) to fulfill the milling requirement to obtain required particle size of flour and proper gelatinization. Moisture content of chili has to be reduced up to 8% (w.b.) in order to achieve maximum output capacity of chili powder production in well-functioning industrial hammer mill. Application of high temperature heating for drying of chili reduces the volatile compounds and thereby reduces the quality of chili powder. Therefore, a method needed to be developed to reduce moisture content of agricultural products during storage with controlled temperature and relative humidity. Low temperature heat pump drying is suitable in removing moisture while preserving quality of the product [11-12]. Thus, the objective of the research was to study the thin layer and deep bed closed cycle heat pump drying characteristics of rice and chili.

Methodology

A HPD system was designed and fabricated using two split type air conditioners. Electronic controllers were design to manipulate the preferable condition in the drying room with higher efficiency of the dehumidifier. Rice and chili were dried in developed HPD system to study the drying characteristics.

Fabrication of HPD system

The heat pump dehumidifier system (

Figure *1*) consists of evaporator unit, condenser unit, primary and secondary control units, main frame and covering chambers. Compressor and expansion valve fixed inside the condenser unit.

Main frame of HPD system was fabricated using metal box bars. The main frame was used to attach all components of HPD system together as one unit. Evaporator and condenser of the split type air conditioner was used as the evaporator unit and condenser unit of HPD system. Refrigerant pipes were fixed between evaporator and condenser units. Upper chamber was fixed above the evaporator unit and the lower chamber was fixed in between evaporator and condenser units. Upper and lower chambers were made to direct the air flow through evaporator to condenser unit. Steel sheets were used to fabricate chambers and airtight sealing sheets were fixed inside of chambers as air sealers.

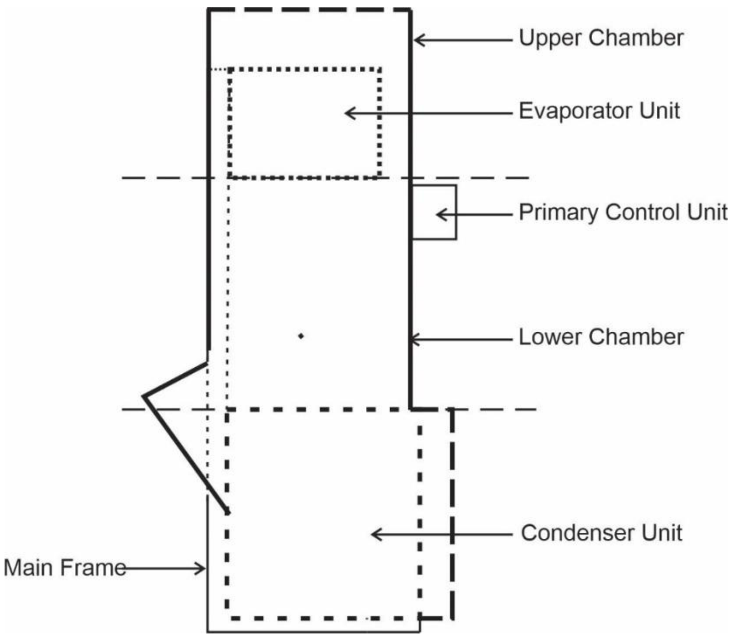

Figure 1: Schematic diagram of the HPD system

Design and fabrication of primary control unit

Primary control unit was designed to improve the efficiency of the HPD system with controlled duty cycle. Default duty cycle had 20 minutes on time and 10 minutes off time. Primary control unit circuit was designed based on PIC microcontroller (Microchip Technology Inc., PIC16F684, USA). Potentiometer was used to alter the duty cycle and Solid State Relay (SSR) was used to switch the HPD system according to the microcontroller. Primary control system was connected to the power supply unit of HPD system to run with specific duty cycle.

Design and fabrication of secondary control unit

Secondary control unit was designed to maintain preferable RH level in storage room with minimum duty cycle of HPD systems and was connected to primary control unit. Secondary control unit was designed based on Arduino microcontroller. RH sensor (Aosong Electrical Co. Ltd., AM2302, China) was used to measure the RH and potentiometer was connected to set preferable RH level on store room. SSR was used to switch the primary control units of the HPD systems.

Establishment of HPD system in the storage room

Two HPD units were mounted on one side of the drying room (

Figure *2*) and each system were connected to the power through primary control units and secondary control unit. Pipe lines were established through the wall to collect condensed water.

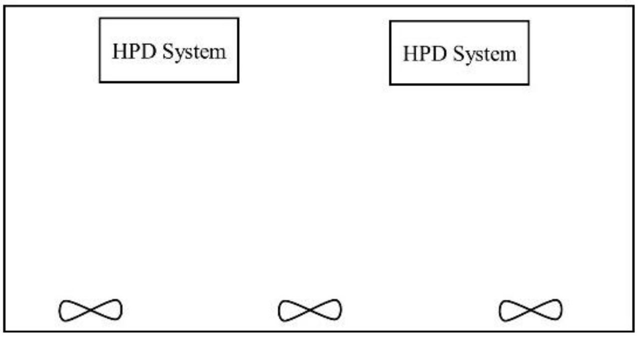

Figure 2: Arrangement of HPD systems and fans

The drying room was modified to have fully air tight condition. Three fans were mounted to enhance the air circulation within the drying room.

Data collection

Data were collected for testing and evaluation of HPD system in empty drying room. Temperature and RH variation of empty drying room were measured during HPD systems were operated. Digital RH meter (Yamato Scientific Co. Ltd., Humidex YH12, Japan) was used to measure the RH and temperature inside the drying room. Volume of the condensed water from empty drying room was measured. Clip-on meter (Fluke 375 True RMS AC/DC Clamp Meter, Netherland) was used to measure the electric current usage by the HPD system.

Rice and chili drying characteristics were evaluated. Moisture content and RH variation with time were recorded with time for both chili and rice. Drying operation were conducted as thin layer drying and filled deep bed drying for both rice and chili. A sample size of 200 g of rice and chili were spread on a top loading electronic balance for moisture determination in thin layer drying. Vertical column and a blower were used to find the deep bed heat pump drying characteristics of rice and chili (

Figure *3*).10 g of samples were collected from top layer of the vertical column ventilator for moisture determination. Weight reduction method [13] and oven dry method [14] were used for the moisture determination of the materials Specific Moisture Extraction Rate (SMER) and Moisture Extraction Rate (MER) were used as performance indicators of HPD system. SMER is defined as the amount of water removed from the materials per energy take by the system (kg-water/kWh) [15]. MER is the dehumidification quantity per unit time (kg-water/h) [16].

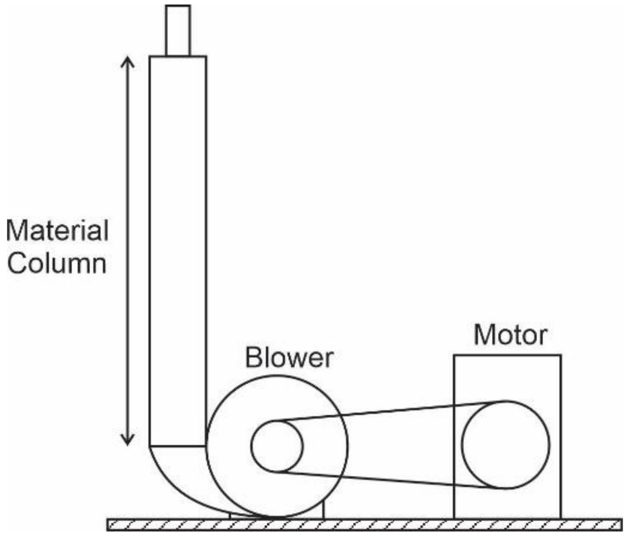

Figure 3: Schematic diagram of vertical column ventilator for deep bed drying

Results and Discussion

The performance of the HPD system was evaluated by the SMER and MER. The fabricated HPD system was used to dry rice and chili and the variation of moisture content throughout the drying processes were studied.

During design and fabrication process special care has been taken to prepare the air circulation inside storage room to maximize efficiency of drying process. Figure 4 shows the air circulation through the HPD system. The purpose of this HPD system is to convert high moist air to low moist air. Evaporator unit reduces the moisture content of entering air which coming through stored product in drying room. Air which is coming from evaporator unit is allowed to flow through the condenser unit. The condenser unit air can absorb heat energy which is coming from refrigerant and increase the air temperature. Air inlet to the condenser unit was designed to compensate the air volume go through the condenser unit. The low moist outlet air temperature was around 30°C.

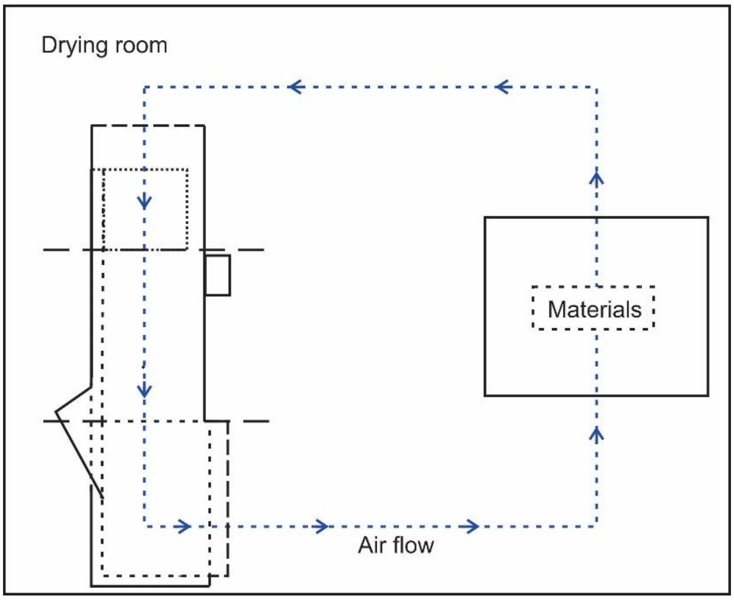

Figure 4: Air flow through the HPD system

Evaluation of the heat pump drying system

The duty cycle of heat pump drying system was 20 minutes on time and 10 minutes off time. Condensed water from HPD system was collected for the duration of one hour. RH and temperature variation inside the store room were recorded with the time in empty drying room.

Initial temperature of the empty drying room was 27°C and after 25 minutes the temperature increased up to 29°C. Initially RH of the empty drying room was 48% and then with the operation of two HPD systems the RH reached to 16% after one hour and remain constant (

Figure 5). Power consumption of HPD system was 956.8 W. Calculated average MER was 1.2 kg-water/h.

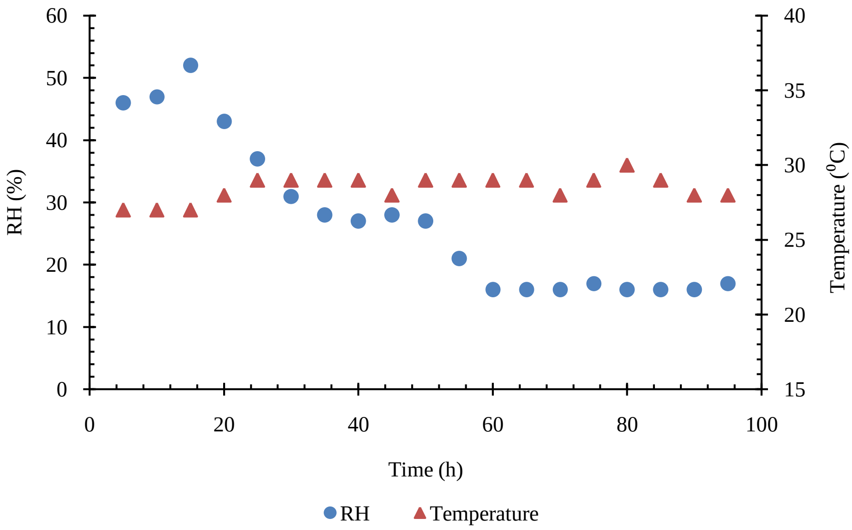

Figure 5: RH variation of the empty drying room with the operation of the HPD system

Moisture content variation of rice and chili in drying room

HPD system was evaluated for the rice and chili drying. In thin layer heat pump drying, the average moisture content of rice was reduced from 15% (d.b.) to 12.4 % (d.b.) after 17 h. In deep bed heat pump drying, moisture content of rice was reduced from 15% (d.b.) to 12.8% (d.b.) drying after 27 h (

Figure 6). The thin layer drying of rice was faster than deep bed drying of rice. Calculated SMER for the thin layer drying of rice was 0.7 kg-water/kWh. Similar SMER value was obtained by Pal and Khan [17]for drying sweet pepper (*Capsicum annuum L.*) in a heat pump drying system.

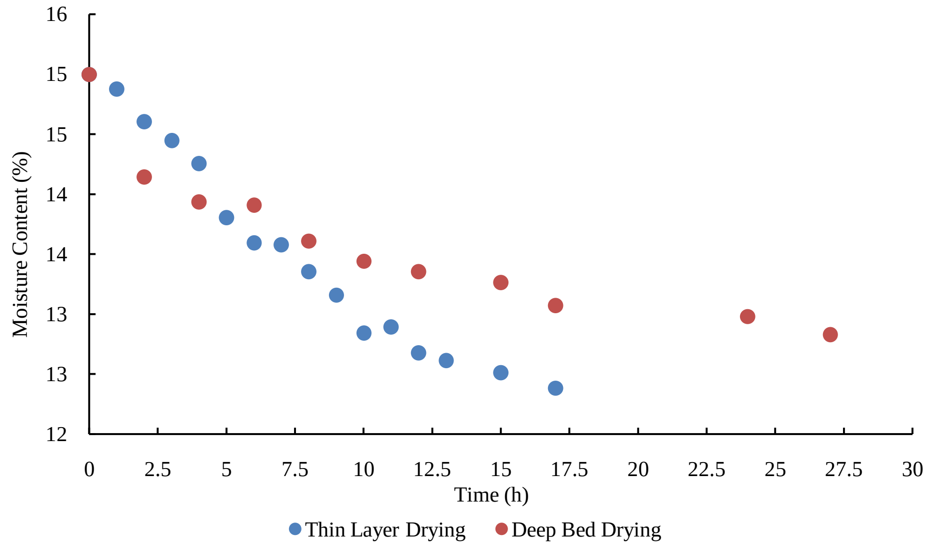

Figure 6: Moisture content variation of rice

The average moisture content of chili was reduced from 13.9% to 4.4% (d.b.) as thin layer drying after 16 h. Moisture content reduces from 13.9% to 6.5% (d.b.) in deep bed drying after16 h of drying in heat pump drying system. Calculated SMER for the thin layer drying of rice was 1.4 kg-water/kWh. Similar SMER values were obtained by Prasertsan [18] in a heat pump drying system evaluation.

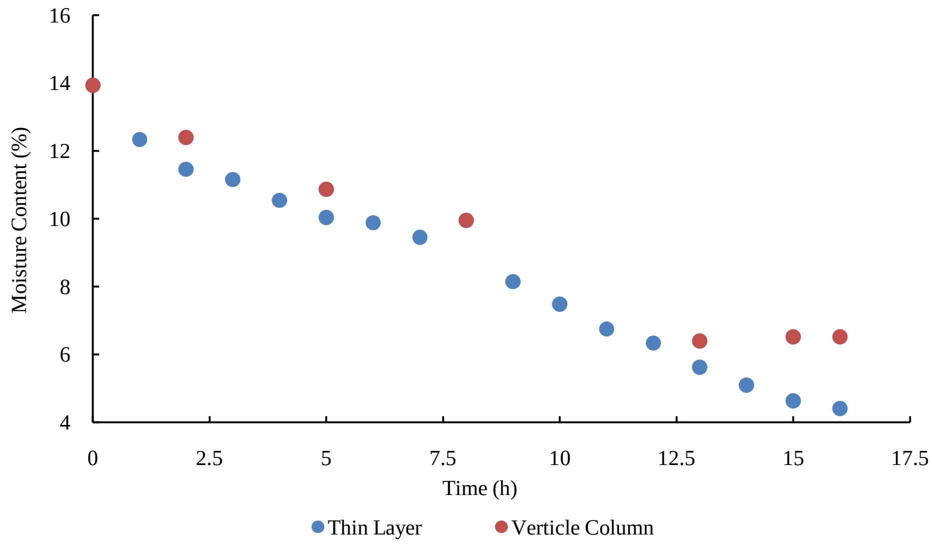

Figure 7: Moisture content variation of chili

Conclusions

The developed closed cycle heat pump drying system performed well with the selected materials. Calculated MER value for heat pump drying system was 1.2 kg-water/h. The SMER for rice and chili was 0.7 kg-water/kWh and 1.4 kg-water/kWh, respectively. The thin layer heat pump drying had higher drying rates than deep bed drying of rice due to high density and less porosity. But heat pump drying of chili did not indicate a significant different drying behavior in thin layer and deep bed drying due to less density and high porosity of chili. The moisture content of rice and chili could be reduced to optimum milling moisture content through heat pump drying. Additional studies can be conducted to optimize the drying conditions in the heat pump drying system and to evaluate the quality characteristics of heat pump drying of rice and chili.

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