Thermal performance of heat pump dryer using R32 as refrigerant.

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Abstract
The objective of this research was to study the performance of heat pump dryer using refrigerant R32 and ginger was selected as testing material. The experiments were conducted under conditions; drying temperature of 45, 50, and 55°C and air velocity of 1.0, 1.5 and 2.0 ms-1. Drying rate, the specific moisture extraction rate, the specific energy consumption, and the coefficient of performance of heat pump were tested. The results revealed that the increment of drying temperature or air velocity resulted in increment of drying rate, power of heat pump dryer, and specific moisture extraction rate whilst specific energy consumption decreased. Additionally, it was revealed that drying temperature or air velocity did not affect the coefficient of performance of the heat pump.

Keywords: Coefficient, Drying, Heat pump

1. Introduction
Advantages of reducing moisture in agricultural products are weight reduction, extended shelf life and convenience for transportation. From the past to the present, there have been many kinds of drying technologies such as drying in the sun, superheated steam drying, infrared drying, vacuum drying, heat pump drying and etc. It is well known that the drying process has a relatively high energy consumption [1]. Presently, most researchers found that heat pump drying technology has highly efficient energy consumption and high product quality [2-4]. However, refrigerants of commercial heat pump dryer are categorized in high global warming potential, GPW, such as R22, R134a, R407C and R410a are having GPW 1,810, 1,430, 1,774 and 2,090, respectively [5]. Recently, refrigerant R32 is a lower GWP refrigerant, GWP is 675, which is an alternative refrigerant that is used as a replacement for high GWP refrigerants. Many researchers studied alternative refrigerants for use in heat pump dryers. In et al. [6] were to compare the study of refrigerants R410a, R32 and L41b for heat pump dryers. They found that the average coefficient of performance, COP, of R32 as a refrigerant for heat pump dryers is higher than R410a at about 5%. Abdullah et al. [7] were to study and test an alternative refrigerant for replacing of refrigerant R410a and they found that a suitable refrigerant for replacing of refrigerant R410a is refrigerant R32. Akhilesh et al. [8] were to develop mathematical model to study performance of heat pump dryers for selecting alternative refrigerants which replace refrigerant R134a. Refrigerants R290, R600a, R32, R152a and R123yf were used in the mathematical model of this study. Results of the study revealed that refrigerant R32 for heat pump dryers had the highest dehydration removal rate.
Dehydration removal rate of heat pump using refrigerant R32 was higher than R134a at 8%, however, COP of heat pump dryer using R152a as refrigerant is the highest. However, past research on performance of heat pump dryers using R32 as refrigerant were still relatively few. Therefore, the objective of this research is to study and test the performance of a heat pump dryer using R32 as refrigerant.

2. Methodology

2.1 Experimental Equipment
This research aimed to develop and test of heat pump dryer using R32 as a refrigerant. The maximum refrigerating effect of the heat pump dryer was 2.64 kW. The main equipment of the heat pump dryer consists of 0.75 kW compressor, 0.05 kW ventilation fan, air damper (3), evaporator (4), external blower, internal condenser (5) and external condenser (6). Schematic diagram of the heat pump dryer shown at Figure 1.

The heat pump dryer operation was started by blower (6) discharged drying air throughout the condenser (3). Drying air was heated by refrigerant in an internal condenser. At the meantime, refrigerant at the condenser outlet would be condensed to saturated liquid. Therefore, drying air flowed through the drying chamber for transferring heat to products. Suddenly, products were heated up when receiving heat from hot drying air and water in products were evaporated to drying air at the drying chamber outlet. Drying air at drying chamber outlet were humidified, whereas, drying air temperature at drying chamber outlet were decreased. Some of the humid drying air was recirculated throughout the evaporator. Moisture in humid air was condensed by evaporator. Refrigerant in the evaporator would be heated to vapor. The refrigerant vapor at the evaporator outlet was sucked and discharged to the condenser by compressor. Meanwhile, dried air at the evaporator outlet flowed and heated at the condenser before entering the drying chamber. The process of heating and dehumidifying the drying air takes place on a cyclic until achieving required products moisture level. Drying air temperature would be controlled by an external condenser equipped at the outside drying chamber and refrigerant cycle would be controlled by 3 solenoid valves. Heating process of drying air by heat pump cycle, solenoid valve was opened to control the refrigerant flow into the internal condenser, whereas, solenoid valve
was closed and refrigerant from the compressor would pass to the external condenser when the temperature inside the drying chamber reaches a certain level.

2.2 Experimental setup
Refrigerant R32 was used for testing of heat pump dryer. The drying air temperature was 45, 50 and 55°C and drying air velocity were 1.0, 1.5 and 2.0 ms⁻¹, respectively. The ginger was dried for a total 4 hours. Initial moisture and weight of ginger were controlled. Temperature, pressure of heat pump cycle, the weight of the ginger, electrical power and energy were recorded by the data recorders. The initial and final moisture of ginger were calculated by AOAC standard. Drying air temperature and velocity had been controlled at starting stage. The drying process was operated until equilibrium stage by investigated on every recorded data. At equilibrium stage, gingers were put in drying chamber and the experiment was conducted continuously for 4 hours.

2.3 Data analysis
The experimental data are used to analyze various parameters. By the last condition used in comparative analysis such as moisture ratio; MR, drying rate; DR, specific moisture extraction rate; SMER, specific energy consumption; SEC and coefficient of performance of heat pump; COP_h. The result was calculated by the following equations:

\[
MR = \frac{M_f}{M_{in}} \\
DR = \frac{m_i - m_f}{T} \\
SMER = \frac{m_i - m_f}{E} \\
SEC = \frac{3.6E}{m_i - m_f} \\
COP_h = \frac{Q_c}{P_c}
\]

Where; \(M_{in}\) = Initial moisture (%dry basis) \\
\(M_i\) = Moisture (%dry basis) \\
\(M_i\) = Initial weight (kg) \\
\(M_f\) = Final weight (kg) \\
\(E\) = Electrical energy consumption (kWh) \\
\(Q_c\) = Heat at condenser (kW) \\
\(P_c\) = Electrical power of compressor (kW)

3. Result and Discussion
The experiments on drying ginger by heat pump dryer using R32 refrigerant were controlled drying air temperature of 45, 50 and 55°C and air velocity of 1.0, 1.5 and 2.0 ms⁻¹, respectively. Results are shown as follows;

Figure 2 shows changing in moisture ratio at each experimental condition. Considering the conditions from the humidity ratio of 0.2 was found that either increasing the drying temperature or drying air velocity would affect the rate of reduction of the moisture content increased. In other words, the drying
The drying air temperature increases, it increases the heat transfer. As the temperature difference of the hot air and the product increases, the product received more heat, the result being that the evaporation of water from the product increased accordingly. Therefore, drying air temperature increases would increase the drying rate. Similarly, increasing the drying air velocity would result in greater heat transfer to the product. Due to heat transfer is primarily a form of convection transfer. For this reason, when the drying air velocity increases, resulting in a heat transfer coefficient increased. Therefore, the product receives more heat. As a result, the drying rate increases as well. Figure 3, if considered under constant drying air temperature conditions, it was found that when the drying air velocity increases approximately 50% would affect in an average increase of drying rate of approximately 10%. Similarly, if the drying air velocity remains to be found that when the drying air temperature increased by an average of 10%, the drying rate increased by 10% as well. Therefore, the drying air temperature had a greater effect on the drying rate than the drying air velocity.

![Figure 2. Moisture ratio at each of the experimental condition.](image-url)
Figure 3. Drying rate at each of the experimental condition under moisture ratio 0.2

Figure 4. Electrical power at each of the experimental condition.

Figure 4 shows the electrical power of the heat pump dryer at each of the experimental condition. The result revealed that an increase in either drying air velocity or drying air temperature would increase the system’s power. Due to the increase of drying air temperature, the compressor had to pressurize the refrigerant to a sufficiently high pressure and corresponding to the saturated vapor temperature to achieve the desired drying temperature. At meantime, it would result in increased heat load on the evaporator. The system had to inject a higher amount of refrigerant. Therefore, the system required more electrical power. In addition, Figure 4 indicated that a 10% increase in drying air temperature results in
a 5-7% increase in electrical power, while a 50% increase in drying air velocity results in a 3-5%, which was found that drying air temperature had a greater effect on electrical power of the heat pump dryer than drying air velocity.

Figure 5. Specific moisture extraction rate at each of the experimental condition

Figure 5 shows the specific moisture extraction rate of the heat pump dryer at each of the experimental condition, an increase in either drying air velocity or drying air temperature would result in an increased specific moisture extraction rate, resulting in a more efficient energy consumption consistent with the specific energy consumption presented in Figure 6. The result in Figure 6 is similar to that of Figure 5, which could be explained by Figures 3 and 4 is that the drying increment was greater than the electrical energy increase. As a result, the specific moisture extraction rate would increase while the energy consumption decreased.

Figure 6. Specific energy consumption at each of experimental condition
Figure 7 shown coefficients of performance the heat pump dryer at each of the experimental conditions. Result found that the change in coefficient of performance of the heat pump dryer had little change. According to the definition, coefficient of performance of heat pump is equal to the total heat reject from condenser divided by power input. Both of these energies vary in approximately the same ratio. Therefore, drying air temperature and drying air velocity had very little effect on the coefficient of performance of the heat pump dryer.

4. Conclusion
Refrigerant R32 was used as the refrigerant for the heat pump dryer and ginger was selected for this experiment. The result revealed that either higher drying air temperature or higher drying air velocity was effective in increase in the drying rate, and the electrical power of the compressor and specific moisture extraction rate, whereas, specific energy consumption was decreased. Moreover, either drying air temperature or drying air velocity had a little effect on the coefficient of performance of the heat pump dryer.

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