Experimental Performance of A Rotary Desiccant Wheel Without Honeycomb Matrix Structure: A Preliminary Study

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Abstract. Experimental investigation of a rotary desiccant wheel is presented in this study. The rotary desiccant wheel without honeycomb matrix structure is tested where silica gel is used as the desiccant material. The dehumidification experiment shows the humidity ratio decreased from 0.0205 kg/kg to 0.0182 kg/kg. Due to it has the potential to be a drying machine, an initial drying experiment was also carried out to see the performance of this machine. The drying process shows the machine can reduce the moisture content of the noodle product from 33.86% to 9.95% in 17 hours. Results show that thermal, regeneration, and dehumidification effectiveness is up to 24%, 14% and 11%, respectively.

1. Introduction
Dehydration involves the simultaneous transfer of heat, mass and momentum. a form of energy penetrates into the product and water vapor is removed by evaporation into the unsaturated gas phase. Evaporation can occur due to heat or by the equilibrium of humidity in the air [1].

A desiccant wheel has been shown good performance for dehumidification. Recently, researchers attract to develop desiccant wheel as it has been proven to conserve more energy. The number of researchers has tried this system for drying agricultural and food products. Atuonwu et al. [2] and Antonellis et al. [3] reported that the desiccant-based dryer has a better performance compared to a conventional convective dryer and the reference technology based on a cooling coil, respectively. Wang et al. [4] integrated heat pump and desiccant wheel for rapid drying application. The paper reported that 30-60 % heat energy was saved by using their proposed hybrid system. In contrast, Abasi et al. [5] reported that integration of desiccant wheel for corn drying increases the total energy consumption by 20.7% due to energy for regeneration. However, energy for regeneration can be supplied from low-cost energy sources such as solar energy as tested by Misha et al. [6].

The rotary desiccant wheel has an ability to absorb water vapor in the air so that it can produce dry air [7]. This system can maintain physical properties and nutrients of the product due to it not using high temperature. The advantages of this system in dehumidification are low initial and operational cost, relatively environmentally friendly, and it has a significant energy saving potential if it uses solar energy and waste heat for its regeneration process [8]

A Honeycomb structure is the most widely used in an experimental apparatus of the desiccant wheel according to literature. The desiccant is impregnated on the honeycomb structure. Another structure is a sinusoidal wave. In addition, instead of honeycomb or sinusoidal structure, O’Connor et al. [9] applied radial plates coated with silica gel that were inserted into a rotary wheel. Their paper aimed to achieve
a low pressure drop desiccant wheel. Even though the pressure drop was low, the porosity of the radial blade design was lower than honeycomb and sinusoidal structure.

This study aims to determine the performance of designed rotary desiccant wheel experimentally. Moreover, the rotary desiccant wheel is tested for drying the post-harvest product such as non-wheat noodles. The characteristic of this product is crack when it is dried under high temperature such as sun drying process. The designed rotary desiccant wheel uses silica gel as desiccant material where the wheel is filled in with silica gel without using honeycomb structure as a medium for attaching silica gel.

2. Methodology

2.1. Experimental apparatus and procedure

An experimental apparatus was designed, as shown in Figure 1. The desiccant wheel is divided into two sections, namely an adsorption section and regeneration section. Each section consists of two segments that were filled with 900 g silica gel of 3-5 mm diameter, as shown in Figure 2. All sections work simultaneously-the ring blower of 0.5 HP carrying ambient air through the sections. A heater of 1 kW with a temperature controller provides hot air for regeneration after the adsorption process. The desiccant wheel was driven by 1 HP electric motor. A combination of the gearbox and chain-sprocket system was installed to rotate the wheel of 0.5 rpm. The airflow rate was regulated by adjusting the valves and measured by a vane-type digital anemometer. The temperatures (T) and relative humidities (RH) were measured by the sensors that were connected to the data logger according to measurement positions in Figure 1. P and V in the figure stand for measurement position and air velocity measurement position, respectively.

![Figure 1. Schematic diagram of experimental apparatus](image-url)

The dehumidification experiment was conducted in 130 minutes, in which the data were taken every 10 minutes. The measurement instruments that are used during the experimental process are listed in Table 1. The heater for regeneration was set in 60°C where average ambient temperature, relative humidity, and air velocity were 32.3°C, 66.9%, and 2.45 m/s, respectively.
As a rotary desiccant wheel potentially to be used for the drying process at relatively low temperature [3], [10], the experimental apparatus was tested to heat sensitive products, i.e. non wheat noodle. The initial moisture content of fresh extrudate of non-wheat noodles was measured with Halogen Moisture Meter. Sample in this measurement method is dried to get a constant value, and then the output value is converted to the moisture content on a wet basis.

The measurement procedure is as follows: the minimum weight of 0.5 g of the sample is placed on the sample tray. When the cover is closed, the sample is heated by a halogen lamp until it reaches 105°C, which is the standard for measuring water content using the Thermogravimetric analysis method.

The non-wheat noodle of 301 g was placed in the chamber that is connected to the discharge of the adsorption section of the wheel. The drying chamber dimension is 400 (l) x 400 (h) x 800 (w) mm. The average inlet and outlet air velocity of the chamber are 1.29 and 1.08 m/s, respectively. The drying process was carried out for 17 hours 22 minutes.

Table 1. Measurement instruments

| Instrument                      | Measured parameter                        | Range                  | Resolution | Accuracy and tolerance |
|---------------------------------|-------------------------------------------|------------------------|------------|------------------------|
| DHT22 DFRobot                   | Air temperature and relative humidity     | -40 – 80°C 0 – 100% RH| 0.1°C 0.1%RH | ±0.5°C ±2% RH           |
| Uni-T Digital temperature humidity meter | Air temperature and relative humidity     | -10 – 60°C 0 - 100% RH| 0.1°C 0.1%RH | ±1°C 20-80% RH: ±5% RH Other: ±8% RH |
| Uni-T Vane-type digital anemometer | Air velocity                         | 0-30 m/s              | 0.99:0.01 100-999:0.1 | ±5%+0.5m/s |
| Loadcell                        | Weight (sample mass)                     | 5 kg                   | 1 gr       | -                      |
| HB43-S Halogen Moisture Analyzer | Moisture content                        |                        | 0.01%      | 0.015% - 0.1%          |

2.2. Effectiveness performance
Effectiveness of desiccant wheel is expressed into thermal, regeneration, and dehumidification effectiveness in equation (1) - (3), respectively.
\[
\varepsilon_T = \frac{T_{o,\text{proc}} - T_{i,\text{proc}}}{T_{o,\text{reg}} - T_{i,\text{proc}}}
\]

\[
\varepsilon_R = \frac{Y_{i,\text{proc}} - Y_{o,\text{proc}}}{h_{f,g}}
\]

\[
\varepsilon_D = \frac{Y_{i,\text{proc}} - Y_{o,\text{proc}}}{Y_{i,\text{proc}} - Y_{o,\text{proc,ideal}}}
\]

T, Y, and h stand for temperature (°C), absolute humidity (kg/kg), and enthalpy (kJ/kg) respectively where \( h' \) is enthalpy at the heater outlet and \( Y_{\text{ideal}} \) is equal to zero when the air is completely dehumidified. Subscript i, o, proc, and reg is inlet, outlet, processed air, and regeneration air respectively.

3. Result and discussion

3.1. Dehumidification process

Figure 3 shows temperature and relative humidity every measuring time during the process. Relative humidity tends to decrease after the air flows through the desiccant wheel. The average result then be plotted in a psychometrics chart. Figure 4 shows the psychometrics plot of the dehumidification process of the desiccant wheel. The adsorption sections inlet and outlet air characteristics are plotted as points P1 and P3, respectively while P5 and P6 represent inlet and outlet of regeneration section respectively.

As shown in Figure 4, air inlet in ambient temperature and relative humidity of 32.3°C and 66.9% respectively had absolute humidity of 0.0205 kg/kg. Water vapor contained in the air decreased in P3 due to being absorbed by the desiccant in the processed air section. Dry bulb temperature increased from 32.3°C in P1 to 35.4°C in P3 due to heat released during the adsorption process and heat remaining from the regeneration process.

The interesting result is seen in the regeneration section because the absolute humidity of outlet air (P6) is lower than inlet air (P5). Theoretically, the water molecules in desiccant pores will evaporate to
the air when the desiccant is being heated. Dash line in P5 is the ideal condition if the regeneration process works properly.

Based on the structural design, there is a possibility of wet air from the adsorption section flowing into the regeneration section. It can be seen from airflow measurement in P3 is half of the airflow that was supplied by the ring blower that is 1.2 l/s in P3 and 2.5 in P2. Another possibility is leakage between section header and the wheel since it is not using mechanical seals.

![Psychometrics plot](image)

**Figure 4.** Psychometrics plot

Table 2 shows detailed characteristics of the air in the inlet and outlet position of the adsorption and regeneration section. Dry bulb temperature and relative humidity are given from measured data when the experiment was conducted.

|               | P1  | P3  | P5  | P6  |
|---------------|-----|-----|-----|-----|
| Dry bulb temp. | (°C)| 32.3| 35.4| 59.9| 49.7|
| Wet bulb temp. | (°C)| 27  | 26.5| 33.8| 30.1|
| Dew point     | (°C)| 25.3| 23.4| 27  | 24.1|
| Relative humidity | (%)  | 66.9| 50.1| 18  | 24.7|
| Absolute humidity | (kg/kg) | 0.0205| 0.0182| 0.0227| 0.019|
| Enthalpy      | (kJ/kg)| 85 | 82.3| 119.5| 99.3|
| Density       | (kg/m³)| 1.142| 1.132| 1.046| 1.081|
| Specific volume | (m³/kg)  | 0.894| 0.9  | 0.978| 0.943|
| Pressure      | (Pa)  | 101325| 101325| 101325| 101325|
3.2 Drying process

The non-wheat noodles with an initial mass of 301 g and 33.86% wet base (wb) water content were dried in the dryer chamber for 1071 minutes. Condition in the dryer chamber is shown in Figure 5. The average temperature in the chamber is 35.97°C, which is higher than the ambient temperature of 29.63°C. Average RH lower than ambient RH, 68.31% compared to 72.07%.

![Figure 5. Temperature and RH in the dryer chamber during the drying process](image)

The mass of the non-wheat noodle sample decreased during the drying process, as shown in Figure 6. The figure shows a reduction in sample weight which indicates a decrease in the sample's moisture content. The sample reached a moisture content of 9.95% wb after it had been dried for 1071 minutes. Whereas with the same time, samples that were placed in an air-conditioned room had a moisture content of 13.2% wb.

![Figure 6. Mass of non-wheat noodle sample during drying process](image)
3.3 Performance
Thermal, regeneration, and dehumidification effectiveness based on equations (1) – (3) is up to 24%, 14% and 11%, respectively. These results seem to be inferior to experiments conducted by the other, as shown in Table 3. It might be because of not all of the desiccant surface area contacts with air. This shows there are problems related to the wheel design.

In the drying process, the humidity ratio did not show a decrease even though RH in the drying chamber was lower than ambient. Therefore the decrease in RH was caused more by an increase in temperature rather than by absorption of desiccants. This problem emphasizes the possibility of issues in construction, design, and measurement instrumentation.

Table 3. Comparison of the desiccant wheel performance

| Desiccant wheel effectiveness (%) | Thermal | Regeneration | Dehumidification |
|----------------------------------|---------|--------------|------------------|
| This work                        | 11-24   | 14           | 11               |
| Misha et al. [6]                 | 37      | 38           | 10               |
| Suvanvisan et al. [11]           | 69.28   | 61.42        | 44.39            |
| Misha et al. [12]                | 49      | 19           | 5                |

4. Conclusion
It is shown in this study that the rotary desiccant wheel without honeycomb matrix structure can be used to reduce water content in the air. However, it has issues in the construction and design in which the desiccant surface should be exposed more so that it can absorb more water particles in the air. Experimental performance of dehumidification process results in a thermal, regeneration, and dehumidification level of effectiveness of 24%, 14% and 11%, respectively. Desiccant wheel effectiveness is lower than other studies because there are problems in the wheel design concepts. This machine needs improvement and development of rotary wheel mechanisms for further study. The drying process result shows that the fresh non-wheat noodle product with an initial water content of 33.86% wb reached a moisture content of 9.95% wb after it had been dried for 17 hours. For further investigation, it is necessary to consider non-dimensional analysis to reduce the parameters of the experiment because many variables can affect the results.

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