Study on the convective drying of potato cube

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Abstract. Drying is a conventional method of food preservation that removes sufficient number of moistures from the food so bacteria, yeast and molds cannot grow. There are several drying techniques can be found in industry such as convective drying and freeze drying. In this study a potato cube is taken into consideration of convective drying experimentally. A small-scale wind tunnel has been designed and fabricated. During experiment, the temperature and mass of the potato cube are measured and recorded. Temperature and velocity of the hot drying air are measured. In order to provide a better analysis computational fluid dynamic is also carried out. The heat and mass transfer analysis during the drying are presented. The results show that the average drying rate of the potato cube is 4.061 gr/hour. The present results can be used to support the necessary information on developing high efficient artificial drier.

1. Introduction

Drying has been known as one of the methods that can be used to preserve food. Drying is used to decrease the moist content of the object. Thus, it can prevent food from material change due to decreasing the microorganism activities. Solar drying is the most conventional drying method known by the human being [1]. In ancient time, natural sun drying had been used to produce raisin by drying grape. Many agricultural products naturally are dried by using solar energy [2]. Drying is a transient complex problem which related to heat and mass transfer and also vapor evaporation. This fact suggests that drying consumes significant number of heat energy and also mechanical energy. Several studies report that nationally energy uses for industrial drying may vary from ten to twenty five percent [3]. Research on drying is very active worldwide. It is reported that around 250 US patents and 80 European patents about drying are registered in every year. This suggests that research on developing more efficient and effective drying is still on going. In order to supply an effective and efficient drying method and equipment also, the answer to heat and mass transfer process of convective drying must be available.

Some studies related to theoretical answer to heat and mass transfer process of convective drying have been reported in literature. Barati and Esfahani [4] reported a new solving method for simultaneous heat and mass transfer during moist decreasing by convection with mango as an object. It is claimed that the work is to occupy the absence in analytical modeling of simultaneously heat and mass transfer during convective drying of foods. Aversa et al. [5] investigated the study on drying simulation by solving all of the governing equations in two-dimensional case. In order to model the vapor concentration on the surface the parameter water activity is employed. The results showed that the model can predict the vapor and fluid transfer where the evaporation and condensation occur.
The above reported studies show that theoretical solving method to simultaneous heat and mass transfer of convective drying plays a significant role in the research related to drying of foods. Recently, Castro et al. [6] reported a complete survey on mathematical modeling of convective drying of fruits. The results reveal that the difficulties on convective drying of foods related to how to solve the correlation on empirical equation for drying parameters solution, the minus of shrinkage effects and three-dimensional modeling. As a note, our research group is developing a continuous solar drying of foods [7]. In order to provide sufficient information on process optimization and development of dryer design, a rigorous theoretical solving method to simultaneous heat and mass transfer of convective drying is needed. In this work, we propose the simplest theoretical approach to simultaneous heat and mass transfer of drying. The objective is to provide an alternative numerical solution to convective drying of food. De Bonis and Roucco [8] reported numerical simulation of drying by using two-dimensional domain to model convective drying of food. Kadem et al. [9] employ the same technique [8] to model the convective drying of wood in three-dimensional domain using commercial code. Murugesan et al. [10] proposed a solution by solving all of the governing equations to model convective drying of brick. In the solid domain, the diffusion equation of fluid and vapor are separated. In the fluid domain, buoyancy effect resulted by temperature difference and concentration difference was considered in the analysis. The model proposed by Murugesan et al. [8] is adopted by Amanifard and Haghi [11] and Suresh et al. [12].

The above literatures show that one of the crucial problems on solving the convective drying simulation is to model the simultaneous heat and mass transfer and followed by change the phase of water into gas on the surface. In order to support a new proposed model experimental data is extremely needed. The objective of this study is to supply experimental information that can be employed to support development of model to solve simultaneous heat and mass transfer and evaporation throughout convective drying of fruits.

2. Method

As mentioned above, here an experimental convective drying is carried out. An experimental convective drying equipment has been planned and manufactured. The experimental equipment is presented in Figure 1. It consists of three main components, they are blower, wind tunnel and measurement apparatus. The blower is equipped with air heater. Thus, the temperature and inlet velocity of the drying air in the wind tunnel can be regulated. The dimension of the wind tunnel is $200 \text{ mm} \times 200 \text{ mm} \times 710 \text{ mm}$. The object dried is placed in the wind tunnel that is made of transparent wall. This wall is designed to make the object can be observed visually. In this study the drying process is controlled only on the top surface of the dried object. Thus, a special object holder is designed. The holder is insulated from other surfaces except from the top surface.

![Figure 1. Experimental apparatus](image-url)
The data acquisition is also designed to the experimental apparatus. It consists of Agilent data logger with 20 channels to measure temperature of the object. The weight of the object is measured using load cell. The specification of the load cell is Aluminium S-type load cell with rate load and rate output is 10 kg and 1.0 ± 0.1 mV/V, respectively. RH meter EL-USB-2-LCD of High Accuracy Humidity, Temperature and Dew Point Data Logger is used to measure temperature and humidity of the drying air. The measurement range and accuracy of the RH meter is 0-100% and ± 2.0, respectively.

In this study the dried object is potato. It is purchased from a traditional local market in Medan city of Indonesia. The potato is sliced to make a cube potato with dimension of 52 mm × 50 mm × 24 mm. Five thermocouples are placed to the object. Three of the thermocouples placed on the top surface and two of the thermocouples are placed inside the cube. The dried object is the placed inside the drying chamber. All of the processes are depicted in Figure 2.

![Image](image1.png)

Figure 2. Preparation of the potato cube and thermocouples position

3. Results and Discussions

Several experiments have been carried out. In this work, the results of a particular experiment will be discussed. The inlet velocity of the drying air was fixed at 0.35 m/s. The parameter history of the drying air is presented in Figure 3.

![Image](image2.png)

Figure 3. Temperature and relative humidity of the drying air
In the figure, the temperature of the drying air, dew point temperature and relative humidity is shown by red line, green line and blue line respectively. The figure shows that in the beginning the temperature start from ambient temperature, about 32°C, increasing gradually to 57.5°C. After reaching the maximum temperature, it is constant during the experiment. At the same time, increasing temperature followed by decreasing Relative Humidity. It starting from 55% and finally reaching 20% relative humidity. Figure 3 reveals that the present experiment is carried out at temperature and relative humidity of 57.5°C and 20%, respectively.

3.1. Temperature history

Temperature history of the object dried is shown in Figure 4. As a note, temperature of the surface is measured at three locations. They are shown by $T_1$, $T_2$, and $T_3$. In addition, temperatures of the potato cube on the side surface are shown by $T_4$ and $T_5$. The initial temperature of the potato cube was 28°C. All temperatures show the same trend. It increases as time increases. In the beginning the gradient of temperature history is bigger than in the last. This is because temperature difference between the potato cube and drying air is still big. As a note, the temperature of the drying air is 57.5°C and the initial temperature is 28°C. This leads to high heat transfer rate from the drying air into the potato cube. This results in significant increasing temperature. However, after the significant temperature gradient, the temperature tends to be flat. This is because the heat transfer rate and heat evaporation in equilibrium. In other words, the heat transfer rate from the drying air is used to evaporate the vapor on the surface. Thus, temperature of the potato cube will constant.

The characteristics of the temperature history on the top surface and on side surface can be examined using Figure 4. Temperatures of the top surface are relatively higher than temperature of the side surface. This is obvious because the heat source comes from the top surface of the potato cube. The temperature difference of the top and the side surface will be a driving force for moist transfer from the inside to the top surface. The moist will move to the top surface and evaporated to the drying air. This process will occur as long as the moist are presence inside the object dried. In other words, the heat transfer from the drying air to the top surface will provide latent heat evaporation. The evaporation on the top surface will decrease the concentration of the vapor on the surface and it will govern the mass transfer rate.

![Figure 4. Temperature history inside the potato cube](image-url)
3.2 Drying rate
Drying rate of the object dried is the calculated and the result is presented in Figure 5. In the figure, only the drying rate in the first two hours are presented. It can be seen, as expected, the drying rate history decreases with increasing time. The maximum and minimum drying rates is 7.416 gram/hour and 2.808, respectively. The average drying rate in the first two hours of drying is 4.061 gram/hour. The drying rate varies between these numbers. It can be seen that the drying process can be divided into three falling rates. The first falling rate occurs from 0 hour to 0.2 hours. The second falling rate is from 0.2 hour to 0.5 hour and the final falling rate is from 0.5 hour to the end drying time.

![Drying rate data](image)

**Figure 5.** Drying rate during the first 2 hours of experiment

4. Conclusions
Forced convective drying of potato cube has been carried our experimentally. The drying process has been controlled only from the top surface of the potato cube. The inlet velocity and the temperature of the drying air have been controlled at 0.35 m/s and 57.5°C, respectively. The conclusions can be drawn here are as follows. The drying rate varies from 7.416 gram/hour and 2.808 gram/hour. The average drying rate is 4.061 gram/hour. The experimental data of the present work can be used to support the data in order to develop heat and mass transfer model during convective drying.

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