Experimental study on the effect of bed aspect ratio to the drying rate of chilli for swirling fluidized bed dryer

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Abstract. Swirling Fluidized Bed Dryer (FBD) has better performance because of the improvement of air flow with less pressure drop. However less study focus on the performance of swirling FBD especially at small-scale. Thus, the objective of this study is to investigate drying characteristics of green chillies at different ratio of chilli, \( R_{\text{chilli}} \) and bed aspect ratio, \( R_{\text{Bed}} \) by the swirling fluidized bed dryer. An electrical blower with 600 W of power was used as a main source to supply air at flow rate of 0.324 kg/s which equals to the velocity at the distributor of 8.25 m/s. The chamber has 400 mm height and 150 mm diameter with maximum capacity of 2 kg. The air distributor used has 67% inclination angle to provide air swirling inside the FBD. It was found that \( R_{\text{Bed}} \) increased from 0.8 to 1.6, the drying performance decreased in which the final moisture ratio was higher at 0.72-0.79 for \( R_{\text{Bed}} = 1.6 \) as compared to better moisture ratio at 0.18-0.24 for \( R_{\text{Bed}} = 0.8 \). The drying rate was at 0.225-0.275 %/min for \( R_{\text{Bed}} = 0.8 \), and 0.075-0.10 %/min for \( R_{\text{Bed}} = 1.6 \). When the \( R_{\text{chilli}} \) increased from 1:1 to 2:1, the drying performance showed slightly decreased. Moisture ratio also slightly increased from 0.18 to 0.24 for \( R_{\text{Bed}} = 0.8 \), whereas from 0.72 to 0.79 for \( R_{\text{Bed}} = 1.6 \). This finding suggest that the \( R_{\text{Bed}} \) has more significant effect than \( R_{\text{chilli}} \).

1. Introduction

The drying process is a process intended to reduce the humidity content of most products, whether industrialized or not, to ensure their storage and transport preservation. Fluidization process is highly attractive for powder drying and wet granular materials. This method has been used industrially it is very common in the drying of coarse materials, pharmaceuticals and food products in various countries around the world [1, 2]. The major parts of the fluidized bed reactors are: the fluidization vessel, the solids discharge, dust separator, the air supply and heat supply. A fluidized bed is called a vessel that contains a bed of solid particles, e.g. sand or catalytically active particles, and a method to introduce gas. It is a machine that dries a continuous flow of moist granular material [3].

Among parameters that affect the drying performance in fluidized bed dryer are the bed aspect ratio, \( R_{\text{Bed}} \) and the chilli ratio, \( R_{\text{chilli}} \). The bed respect ration, \( R_{\text{Bed}} \) is define as the ratio of high of the bed to the diameter of the bed. Meanwhile, the chilli ratio, \( R_{\text{chilli}} \) define as the ratio of chilli length to the chilli diameter. Lower \( R_{\text{Bed}} \) and smaller \( R_{\text{chilli}} \) of particles improved the drying rate of the samples. However, there are no studies in drying chilli at different \( R_{\text{Bed}} \) together with \( R_{\text{chilli}} \) for Swirling FBD.
Thus, the objective of this study is to investigate drying characteristics of green chillies at different ratio of chilli, $R_{chilli}$ and bed aspect ratio, $R_{bed}$ by the swirling fluidized bed dryer.

2. Methodology

Figure 1 shows the experimental setup of swirling fluidized bed dryer. For the blower, 600 W blower was used as a main source to supply air at flow rate of 0.324 kg/s and the velocity at the distributor was 8.25 m/s. The chamber has 400 mm height and 150 mm diameter with maximum capacity of 2 kg. The air distributor used has 67% inclination angle to provide air swirling inside the FBD.

Table 1 shows the variables in conducting the experiment for drying the samples using the fluidized bed dryer. Approximately, 2 kilograms of sample green chillies were used to determine the rate of drying by the fluidized bed dryer. 2 kilograms of green chillies have been purchased. Both ends of the chillies were removed and only the middle portions, which resemble a cylindrical shape, were used to produce the required samples. Samples were prepared at two $R_{chilli}$ of 1:1 and 2:1, at 1 kg and 2 kg respectively. Figure 2 shows the sample of chilli with $R_{chilli}$ of 2:1. After preparation, chillies were kept in a plastic container and washed in order to make uniform moisture distribution before commencement of experimentation.

Table 1. The variables of the experiment in drying the chilli.

| Weight | Length to diameter ratio of chilli ($R_{chilli}$) | Length to diameter ratio of chilli ($R_{chilli}$) | Bed aspect ratio ($R_{bed}$) |
|--------|-----------------------------------------------|-----------------------------------------------|----------------------------|
| 1 kg   | 1:1                                           | 2:1                                           | 0.8                        |
| 2 kg   | 1:1                                           | 2:1                                           | 1.6                        |

The experiment was conducted to investigate the rate of drying of the samples and performance of the fluidized bed dryer that have been fabricated. Figure 3 Shows approximately 1 kg of sample was placed in the fluidized bed column. The swirling of the bed was observed and recorded.

The air flow of 8.25 m/s from the blower was on during the drying process so that it will evaporate the moisture content of the samples. Clamper was use to clamp the chamber tightly so that no airflow moves out from the chamber because there was a small gap between the chamber and the aluminium
blocks. In this experiment, high weight differences were required to indicate the weight loss of the samples by the FBD. Other than that, low moisture ratio gives good swirling effect to the bed. Lastly the graph of moisture ratio and weight loss vs time was plotted for every ratio of the samples.

Figure 2. Sample of chilli with length to diameter ratio of 2:1.

Figure 3. Drying of chilli sample.

After preparation, chillies were kept in a plastic container and washed in order to make uniform moisture distribution before commencement of experimentation. Equation (1) is the formula on how to get the value for the length to diameter ratio of chilli ($L_{chilli}/D_{chilli}$),

$$R_{chilli} = \frac{L_{chilli}}{D_{chilli}}$$  \hspace{1cm} (1)

where $L_{chilli}$ is length of chilli (m), and $D_{chilli}$ is diameter of chilli (m). For the bed height, 1 kg of chilli consist of 12 cm shown in figure 4 of bed height. For 2 kg of chilli, the bed height was 24 cm shown in figure 5. The diameter of the bed was 15 cm. The bed aspect ratio, ($R_{Bed}$) need to calculate and the value is shown in table 1. $R_{Bed}$ is shown in equation (2).

$$R_{Bed} = \frac{H_{Bed}}{D_{Bed}}$$  \hspace{1cm} (2)

where $H_{Bed}$ is height of the bed (m), and $D_{Bed}$ is diameter of the bed (m). Other than that, low moisture ratio gives good swirling air flow motion to the bed. The weight losses, $W_l$ are calculated by subtracting the weight of the samples before and after drying for every 5 minutes throughout 40 minutes shown in equation (3). Lastly the graph of moisture ratio ($M_r$) and weight loss ($W_l$) vs time was plotted for every ratio of the samples.
\[ W_i = W_n - W_{n+1} \]  

(3)

where \( W_n \) is weight of chilli at specific time (kg), and \( W_{n+1} \) is weight of chilli at subsequent time in kg. \( M_r \) is calculated based on equation (4).

\[ M_r = M_{r_n} - \frac{W_n - W_{ds}}{W_{ds}} \]  

(4)

where, \( W_n \) is weight of sample at specific time in kg, \( W_{ds} \) is weight of dried sample, \( M_{r_n} \) is moisture ratio at specific time (%). The drying rate \( (D_r) \) is dividing the difference of the moisture ratio of two consecutive samples by the drying duration. It is calculated based on equation (5).

\[ D_r = \frac{M_{r_i} - M_{r_{n+i}}}{t} \times 100 \]  

(5)

where, \( D_r \) is drying rate (%), \( M_{r_i} \) is moisture ratio at specific time, \( M_{r_{n+i}} \) is moisture ratio at subsequent time, and \( t \) is drying duration (s).

3. Results and discussion

3.1. Effect of \( R_{chilli} \) and \( R_{Bed} \) on the drying rate of fluidized bed dryer

Figure 6 shows the results of weight loss and moisture ratio for different \( R_{chilli} \) and \( R_{Bed} \). Red lines show the moisture ratio, whereas the blue bars show the weight loss. It should be noted that the blue bars are weight loss in each interval, and not the overall weight of the sample. On the top side of the figure is the result for \( R_{Bed} = 0.8 \), and at the bottom side of the figure is \( R_{Bed} = 1.6 \). On the right side is \( R_{chilli} \) at 1:1, and on the left side is \( R_{chilli} \) at 1:2.

It was found that when \( R_{Bed} \) increased from 0.8 as shown in figure 6(a) and (b) to 1.6 as shown in figure 6(c) and (d), the drying performance decreased in which the moisture ratio at 40 minutes was higher at 0.72-0.79 for \( R_{Bed} = 1.6 \) as compared to better moisture ratio at 0.18-0.24 % for \( R_{Bed} = 0.8 \). This is because higher \( R_{Bed} \) means the bed has higher bed pressure drop that makes frictional shear forces within the bed loading increases. In term of drying rate, the drying rate was at 0.225-0.275 \%/min for \( R_{Bed} = 0.8 \), and 0.075-0.10 \%/min for \( R_{Bed} = 1.6 \). This result is consistent with the study by Sadaka et. al, which concluded that the overall drying rate decreases with increases in aspect ratio or \( R_{Bed} \) [4]. This suggests that \( R_{Bed} \) has significant effect on the drying performance even for swirling FBD at small-scale.
When $R_{chilli}$ increased from 1:1 as shown in figure 6(a) and (c) to 2:1 as shown in figure 6(b) and (d), the drying performance slightly decreased. Moisture ratio slightly increased from 0.18 to 0.24 for $R_{Bed} = 0.8$, whereas from 0.72 to 0.79 for $R_{Bed} = 1.6$. This is because $R_{chilli} = 1:1$ has smaller surface area and therefore particle has more contact surface area with the air, and particles dry faster as compared to $R_{chilli} = 2:1$. This result is consistent with the study by Oluleye et al., smaller $R_{chilli}$ will dry faster because smaller grains show high resistance to airflow therefore reducing the fan outputs and also increasing the amount of moisture reduced in the grains [5]. However, $R_{chilli}$ has less effect as compared to $R_{Bed}$.

Thus, $R_{Bed}$ has more significant effect than $R_{chilli}$ on the drying performance of swirling FBD at small-scale for chilli. When $R_{Bed}$ increased two times, moisture ratio decreased 53-55%, whereas when $R_{chilli}$ increased two times, moisture ratio only decreased 6-7%.

4. Conclusion

i) When $R_{Bed}$ increased from 0.8 to 1.6, the drying performance decreased in which the final moisture ratio was higher at 0.72-0.79 for $R_{Bed} = 1.6$ as compared to better moisture ratio at 0.18-0.24 for $R_{Bed} = 0.8$. This is because higher $R_{Bed}$ means the bed has higher bed pressure drop that makes frictional shear forces within the bed loading increases.

ii) The drying rate was at 0.225-0.275 %/min for $R_{Bed} = 0.8$, and 0.075-0.10 %/min for $R_{Bed} = 1.6$. This suggests that $R_{Bed}$ has significant effect on the drying performance even for swirling FBD at small-scale.

iii) When $R_{chilli}$ increased from 1:1 to 2:1, the drying performance slightly decreased. Moisture ratio slightly increased from 0.18 to 0.24 for $R_{Bed} = 0.8$, whereas from 0.72 to 0.79 for $R_{Bed} =
1.6. This is because $R_{\text{chilli}} = 1:1$ has smaller surface area and therefore particle has more contact surface area with the air, and could dry faster.  
iv) However, $R_{\text{Bed}}$ has more significant effect than $R_{\text{chilli}}$. When $R_{\text{Bed}}$ increased two times, moisture ratio decreased 53-55%, whereas when $R_{\text{chilli}}$ increased two times, moisture ratio only decreased 6-7%.

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References
[1] F. ABERUAGBA, J.O.O., K.R. ADEBOYE, M.A. OLUTOYE, Fluidization Characteristics of a Prototype Fluidized Bed Reactor Leonardo Journal of Sciences, 2005(6): p. 29-41.
[2] Halim, L.A., et al., Preliminary Study on Drying of Stingless Bee Pot Pollen Using Novel Fluidized Bed Dryer with Swirling Distributor. MATEC Web Conf., 2018. 225: p. 04007.
[3] Sivakumar, R., et al., Fluidized bed drying of some agro products – A review. Renewable and Sustainable Energy Reviews, 2016. 61: p. 280-301.
[4] Sadaka, S., K. Luthra, and G.G. Atungulu, Effects of Aspect Ratio, Drying Temperature and Drying Duration on the Performance of a Custom-Made Fluidized Bed Drying System, in 2018 ASABE Annual International Meeting. 2018, ASABE: St. Joseph, MI. p. 1.
[5] Oluleye A. E, O.A.A., Anyaeche C.O., Design and Fabrication of a Low Cost Fluidized Bed Reactor. 2012. 3: p. 24-35.