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Drying process of black pepper in a swirling fluidized bed dryer using experimental method

N F M Roslan and A S M Yudin*

Energy and Sustainability Focus Group, Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

*E-mail: shukrie@ump.edu.my

Abstract. Black pepper (piper nigrum) is one of the well-known spices extensively used worldwide. Drying is the most popular methods of preserving the black pepper. Unfortunately, this operation may negatively influence product quality. Moreover, due to the high heat capacity of water, drying is usually a long-lasting and energy-intensive process, thus new drying techniques are continuously being sought. Fluidized bed dryers have been applied to dry raw materials due to the advantages of good mixing efficiency and high heat and mass transfer rate. In order to control and optimize the drying process of fluidized bed dryers, it is necessary to develop reliable methods to measure the moisture content of solid particles in the bed. For this project we dried the black pepper using two methods which is drying under sun drying and swirling fluidized bed dryer using heater. The temperature for both drying will be the same. Then, the characteristic and the drying moisture ratio of the black pepper were compared between these two drying methods. The performance of the swirling fluidized bed dryer was evaluated based on the percentage of moisture content of loss reduction. The time taken for this drying is 10 hours, which considered as 1 day of drying process. The percentage of moisture content loss reduction is 57.9%. The moisture ratio after 10 hours of drying is 0.3420. In conclusion, drying using swirling fluidized bed dryer is the new technology that can be used in drying industry.

1. Introduction

Drying is the process of the removal of water (moisture) from hygroscopic materials at low to medium moisture contents (normally <30% wet basis) by means of evaporation. When the moisture content of the agricultural products is high (usually >50% wet basis) the process of removal of moisture is referred to as dehydration [1]. The examples of the products that are dried include cereals, oilseeds, legumes, and some processed foods; and examples of the products that are dehydrated include fruits, meats, and vegetables.

Conventional method is drying under sunlight or solar drying. Natural method is drying under sunlight on sunny day. The material to be dried is placed directly under hostile climate conditions like solar radiation, ambient air temperature, relative humidity and wind speed to achieve drying. In direct solar dryer, the materials to be dried is placed in an enclosure, with transparent covers or side panels. Heat is generated by absorption of solar radiation on the product itself as well as the internal surfaces of the drying chamber. This heat evaporates the moisture from the drying product and promotes the natural circulation of drying air. In the open sun drying, the products are spread on the concrete floor and are raised platform which are contaminated by dust, dirt, insect's damaged and other pollutants, thereby, degrading the quality of the products [2]. Other than that, sun drying method involves multiple works such as heaped and covered the product at night or during rainy weather that can cause re-wetting [3].

The quality the products will further be degraded by the delays drying when a rainy day or long drying time and the moisture content of drying products are not uniform, which causes the mould growth [4]. Furthermore, time taken to remove the moisture content by using conventional method is to long in around one to six hours one to ten days. Since Malaysia has monsoon season between March to August, it is also will disturb the drying process and the drying rate become longer. Swirling fluidized bed drying is proposed to improve the drying of black pepper.

Fluidized bed dryer is a new method that were used nowadays for a better quality of the output products. It offer significant advantage like high heat and mass transfer. Undergo uniform moisture reduction with less drying time and high drying rate. The loss of moisture weight reduction from the wet solid per unit time (drying rate) is the method to measure the dryer performance. Swirling fluidized bed dryer has four stage of swirling patterns. Firstly, packed regime: in the beginning, there are none movement in the bed. At this condition, resistance of bed towards air flow is at its peak due to the particles are stick together. Secondly, two layer: then, bottom layer particle begin to swirl while upper layer having vibration condition. At this regime, tangential velocity component was decayed and at certain height, superficial velocity is insufficient to create any swirling in the bed. Thirdly, wave motion: at this region, the bed having partial swirl. Swirling motion extends over a certain area of this bed, while the remaining area is static. The swirling area moved black paper to the static area and the motion stopped, while triggered second swirling motion at static area. Lastly, fully swirling: as the black paper become drier, stable swirling pattern was finally reached [4]. Both wave motion and fully swirling condition occurred due to the swirling velocity finally becomes higher as a result of lower bed weight as a result of continuous moisture transfer.

Considering the disadvantages of the open sun drying, an attempt has been made in this study to investigate the drying characteristic of black pepper by using conventional method of sun drying and also to investigate the drying characteristic of black pepper inside the swirling fluidized bed dryer. Lastly, to compare the drying of black pepper by using conventional method and swirling fluidized bed drying.

2. Drying technology of black pepper

2.1. Drying under solar

The drying process under sun drying is a conventional method for harvesting and processing for black pepper which is the biggest spices in the world. Black pepper are from unripe green berries from pepper plant. Matured green spikes with 1 or 2 berries in the spike starting to yellow are harvested for the preparation of black pepper. In a traditional pepper garden where vines are about 3m high, harvesting of spikes on the upper canopy is done using a ladder. Blanching is sometimes practised by immersing the berries in hot water, of about 90 °C, for 2-3 minutes prior to drying. This reduces microbial load, washes off dust particles, and helps in drying pepper faster. Blanched, dried black pepper has a glossy appearance and a better, more uniform colour [5]. Good sun-dried black pepper should not contain more than 12% moisture. Generally, the conversion rate is about 33% of the green berries, but it can vary from 29 to 36% depending upon the variety and maturity at time of harvest. After blanching, the product can be dried to a uniform moisture level (8–10%) within three days in full sunlight. The end product has a shiny black colour. First, determine the PPO (polyphenol oxidise) activity, reduced weight percentage, and the changes in colour and appearance of green pepper berries after blanching and sun drying, and we found that PPO activity decreased dramatically after blanching, whereas the rate of browning and water loss increased [5]. The fresh pepper berries was then subjected to heat treatment with hot water for 1, 2, and 3 minutes at 80, 90, and 100 °C, respectively. The fresh pepper berries was then compared with the pepper berries soaked in boiled water for 10 minutes.

Blanching is known to activate the phenolase, which is responsible for producing the black colour of pepper berries. The black colour that the pepper acquires upon drying is due to the oxidation of colourless phenolic compounds present in the skin. The lower the blanching temperature and the shorter the sun drying, the lighter the sample colour. The unblanched pepper berries remained yellow-green during sun drying for 16 hours.

2.2. Tunnel dryer

The Tunnel dryer is a direct continuous type of dryer. It is a largest scale dryer. In this dryer, the materials that to be dried are sent to the air heated tunnel for drying purpose. The material is entered at one end and the dried material is collected at the other end of the tunnel. The outgoing material met the incoming air to ensure maximum drying and the outgoing air contacted the wettest material so that the air was as nearly saturated as possible. One of the doors of the tunnel is opened and the materials to be dried are placed to the trolleys and trucks are pushed slowly in the tunnel and then door is closed. Hot air is circulated and passed through the rail truck and perforated trolleys. The hot air then followed is recirculated with the help of fans and the material becoming dried. The moist air is passed out through the exhaust after completion of drying. The door is opened and the trolleys are taken out of the funnel and some new trolleys with the wet materials are introduced into the trucks and the process is repeated [6].

2.3. Swirling fluidized bed dryer

The optimal method for controlled, gentle and even drying of wet solids. Higher throughput with better quality for a range of products (having different shape, bulk density, physical and chemical properties) can be achieved in FBD drying by using medium and low grade thermal energies. The drying process with fluidized bed drying reduces the drying time in the drying oven by approximately twenty times. In addition, fluidized bed drying provides controlled and uniform drying conditions compared to the uneven drying in trays [7]. It must be ensured that drying always takes place in a thermodynamic equilibrium.

Acts as a high mixing ability and improved solid-gas contact to shorten the drying time of products. Hydrodynamic study was conducted for three beds loadings of 1.0 kg, 1.4 kg at a drying temperature of 90 ºC. The SFBD has shown excellent potential to dry the pepper with a relatively short drying time compared to the conventional method [8]. It was found that bed higher bed loading of wet pepper requires longer drying time due to higher amount of moisture content in the bed. In SFBD method, when air flow was introduced through the bottom of a bed in SFBD, solid particles become suspended (at least at drag force equal to gravitational force) and behave fluid-like and high solid-gas contact in the bed allows vigorous mixing [4]. As the drying cycle time increase, the moisture content decrease. When the moisture content is high, there is pre-heating period [9].

2.4. Drying parameter

The drying parameter that used to calculate the drying result is moisture content and moisture ratio. It is important to calculate the moisture content reduction loss to get the result of the experiment. Drying curves obtained under controlled conditions provide important information regarding the water transportation mechanisms, and they are used in the determination of the effective diffusion coefficient. The moisture content (M) at any time of drying (%), was calculated using equation (1):

$$M = \frac{W_i - W_d}{W_i} \times 100\% \qquad (1)$$

The reduction of moisture ratio with drying time was used to analyse the experimental drying data. Moisture ratio (MR) represents the amount of moisture remaining in the samples reported to the initial moisture content. It was calculated using equation (2):

$$MR = \frac{M - M_e}{M_0 - M_e} \qquad (2)$$

The equilibrium moisture content (M_e) were determined by drying until no further change in weight was observed for the samples in each treatment and drying conditions [10].

3. Experimental setup and procedure

3.1. Conventional drying experiment

The experiment was carried out under the sunlight or solar. The black pepper weight is 1008 grams was dried on the drying mat that placed on the table that exposed to the sunlight without any disturbance such as building. The drying black pepper was conducted to investigate the drying time and the moisture ratio content that dried from the black pepper. A fresh black pepper was used to ensure the moisture content are neglected as shown in figure 1.

Figure 1. Fresh black pepper that were used in experiment.

The drying mat basically from the wire gauze so that the air surrounding can propagate around the black pepper as shown in figure 2.

Figure 2. The black pepper were placed on wire gauze.

The temperature of the surrounding was recorded using temperature data logger and the weight of the black pepper before and after the drying was recorded to determine the moisture ratio that were loss using electronic weighing scale.

3.2. Swirling fluidized bed drying experiment and setup

The fluidized bed apparatus is located at Energy and Sustainability Focus Group laboratory, Universiti Malaysia Pahang. The photograph of the experimental setup is shown in figure 3. In order to scientifically investigate the performance of the distributor configurations and its effect to the bed material, the following requirements are specified such as fluidized bed system that allows interchangeability of the distributor, clear silica glass cylinder to enable visualization of studies, pressure drop measurement and the velocity of the air flow.

The fluidization column consists of transparent cylindrical silica glass which has 108 mm internal diameter, 5 mm thickness and 310 mm length. An acrylic plate that has the same diameter with the glass column's flange was mounted at the bottom. The air flow was controlled by the controller that controls the speed of the blower between 0 and 50 Hz speed range. Fluidization air was generated from a blower and it was heated to a desirable temperature using an electrical heater. The temperature and humidity sensor was installed at the outlet of the bed to measure the temperature and relatively humidity of the exhaust air.

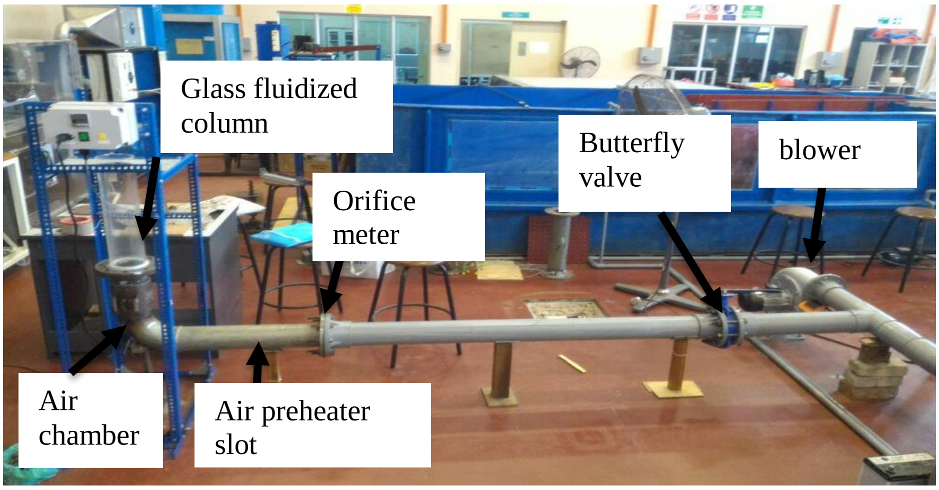

Figure 3. The fluidized bed dryer setup.

The black pepper weight of 1008 grams was dried in the swirling fluidized bed dryer. The weight of black pepper was measured using electronic weighing scale before put in the swirling fluidized bed dryer to calculate its moisture content. The blower was turn on and the speed of the blower was 4.26 m/s. The heater was turn on but the temperature on the heater must not higher than 40 °C, so that the temperature of the conventional drying is the same with the temperature of the swirling fluidized bed dryer. After the black pepper was dried, the black pepper was weigh again to calculate the moisture ratio and to calculate moisture content loss reduction.

3.3. Distributor

A design of air distributor made of aluminium with 115 mm diameter and 8 mm thickness was tested in the experiments. The distributor geometry was modified to introduce novel swirling distributor by making the edge opening with 45 inclined air intakes as shown in figure 4.

Figure 4. The 45° distributor that used in the fluidized bed dryer.

4. Results and discussion

4.1. Conventional drying (sun drying)

By considering previous sun drying that was done by other researcher, the moisture content that should be removed is 12%. For conventional drying, the black pepper was weight first and 1008 grams black pepper was dried and the moisture content of the black pepper that should be loss (x) were calculated as shown in equation (3):

$$x = \frac{12}{100} \times 1008\ grams = 120.96\ grams \tag{3}$$

The drying of black pepper was also affected by surrounding temperature. The average temperature that recorded was 35 °C. Figure 5 shows that the condition of black pepper before conventional drying. The temperature of the surrounding was recorded using temperature data logger. The drying time taken for conventional drying is 7 days. Figure 6 shows the condition of black pepper after 7 days of drying. The remaining weight of the dried black pepper is 476 grams. Table 1 shows the weight of the black pepper for each day drying and its moisture ratio using the calculation of moisture ratio.

Figure 5. Condition of black pepper before drying.

Figure 6. Condition of black pepper after 7 days of drying.

Table 1. the weight before, after and moisture ratio of conventional drying for each day.

Time (Day)	Weight before (g)	Weight after (g)	Moisture ratio
1	1008	879	0.8546
2	879	764	0.7249
3	764	615	0.5570
4	615	547	0.4803
5	547	499	0.4262
6	499	482	0.4070
7	482	476	0.4003

Figure 7 shows the graph for the moisture ratio and temperature vs the time taken for conventional drying. From the graph, the highest temperature recorded was on day 3 which is 37 °C and the moisture ratio is decreasing as the time (day) of drying is increasing.

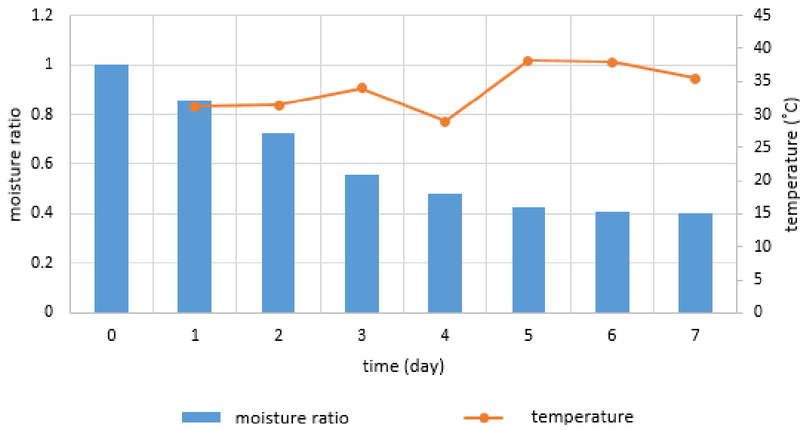

Figure 7. The moisture ratio and temperature vs time taken for conventional drying.

The percentage of moisture content of loss reduction of drying black pepper using conventional drying is 52.7%. The visualisation of the black pepper after drying is the colour does not shiny because the product was spoilt because was dried on the surrounding so there may be some impurity on the black pepper. The colour of black pepper also blackish grey.

4.2. Swirling fluidized bed drying

The weight of the black pepper used in the swirling fluidized bed dryer setup is 1008 grams. Figure 8 shows the condition of black pepper in swirling fluidized bed before drying process took place. The time taken for drying in a swirling fluidized bed only 10 hours. For the swirling fluidized bed dryer, the temperature of the hot air from the heater was in the range of 33 °C and 38 °C. Figure 9 shows the condition of black pepper in a swirling fluidized bed dryer during drying process.

Figure 8. Condition of black pepper before swirling.

Figure 9. Condition of black pepper when swirling.

During the drying process in a swirling fluidized bed, the black pepper swirls in a spiral motion in a clock-wise direction. Air entrainment at 45° inclination angles provides swirling flow thus improve drying time to only 10 hours. The mechanism of swirling motion that occurs rapidly at the bottom of the bed is due to the non-uniform air formation from the tangential air flow through the inclined slots. The chaotic air formation induced the black pepper particles in clock-wise swirling motion which the pattern is similar to blenders. However, due the black pepper weight, the swirling motion is weakened as the air bubble progressed upward through the dense black pepper. Instead, the air erupted and the occurrence is randomized across the bed surface. Table 2 shows the weight and moisture ratio of the black pepper during for 2, 4, 6, 8 and 10 hours in the swirling fluidized bed drye. Figure 10 shows the moisture ratio and temperature of the heater versus time taken during drying in the swirling fluidized bed.

Table 2. The weight and moisture ratio of black pepper for 2, 4, 6, 8 and 10 hours in swirling fluidized bed dryer.

Time (hour)	Weight before (g)	Weight after (g)	Moisture ratio
2	1000	920	0.9091
4	920	783	0.7534
6	783	547	0.4852
8	547	451	0.3761
10	451	421	0.3420

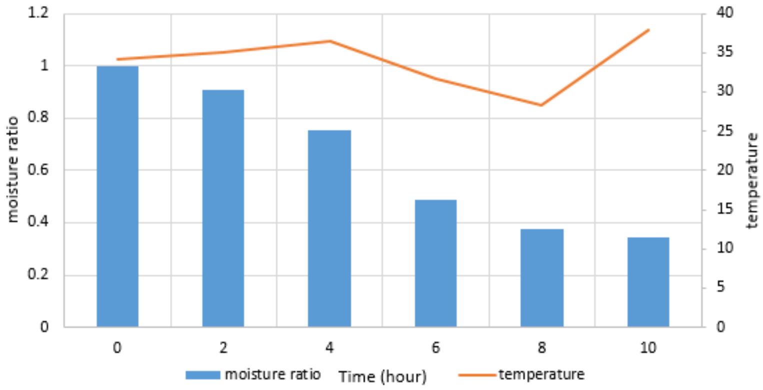

Figure 10. The moisture ratio and the temperature of the heater vs time taken for drying black paper in swirling fluidized bed dryer.

The percentage of moisture content reduction at the end of drying is calculated at 57.9%. Figure 11 shows the visualisation black pepper using swirling fluidized bed dryer at the end of drying time. The colour of the black pepper is pure black. The shape also round and shrink and the black pepper also shiny shows that the quality is better because there is no impurities.

Figure 11. The visualisation of result of drying black pepper using swirling fluidized bed dryer.

4.3. The comparison between conventional drying and swirling FBD

Table 3 shows the comparison between conventional drying and swirling fluidized bed drying. The conventional drying takes more time because the drying using the sunlight. It can be done effectively from 9 am to 4 pm. The rest of the time is idle. The weather also affect the drying especially in raining day, the drying process is impossible to be conducted due to high moisture content in the air. The conventional drying also should be done in an open field. Trees, buildings and other structures may block sunlight and hinder the drying process. So, the drying using conventional takes more time than swirling fluidized bed drying.

Table 3. The comparison of the conventional drying and the swirling fluidized bed dryer.

Comparison	Conventional drying	Swirling FBD
Remaining weight after drying(g)	476 g	421 g
The moisture content loss reduction	52.7%	57.9%
Drying time	7 days	1 day (10 hours)

5. Conclusion

In short, it can be concluded that the time taken for drying the black pepper by using conventional drying is 7 days, while drying using swirling fluidized bed dryer is reduced to only 10 hours. Its shows that the drying time using swirling fluidized bed is faster than drying using conventional method. The quality of the black pepper after drying using fluidized bed dryer also shows better quality because the black pepper colour is dark black and it look shiny shows that no impurities in the black pepper. The remaining weight for the dried black pepper by conventional drying is 476 grams while by swirling fluidized bed dryer is 421 grams. The percentage of the moisture content reduction for swirling fluidized bed dryer which is 57.9% meanwhile the percentage of moisture content reduction for conventional drying which is only 52.7%.

In general, the drying of black pepper in a swirling fluidized bed dryer is more efficient and high quality than conventional drying. Hence, the three objectives of this project which is to investigate the drying characteristic of black pepper by using conventional method sun drying, also to investigate the characteristic of black pepper by using swirling fluidized bed dryer and to compare drying of black pepper performance by using conventional method and swirling fluidized bed drying was achieved.

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