International Journal of Manufacturing & Industrial Engineering – IJMIE
Volume 1: Issue 2 [ISSN: 2374 -1589]
Publication Date : 25 June 2014

Drying Kinetics of Black Pepper Dried in A Spouted Bed Dryer with or without Draft Tubes

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Abstract— **Drying of black pepper has been studied in a lab scale spouted bed dryer. Experiments were carried out in a spouted bed dryer either with or without internal devices. The two different internal devices of the dryer are namely non porous draft tube and porous draft tube. Effect of drying temperature, type of drat tube, diameter of draft tube and stagnant bed height on drying kinetics were analyzed. The highest drying rate was achieved when black pepper was dried without draft tube at highest drying temperature. Drying kinetics of black pepper in spouted bed dryer indicated only induction and falling rate periods, without existence of the constant rate period.**

Keywords*— *black pepper, spouted bed, draft tube, drying kinetics

I. Introduction

Spouted beds are gas-particle contactors which are suitable to handle coarse particles such as Group -D particles in the Geldart classification of particles[1]. Heat carrying gas (hot air) is injected vertically upward through the centrally located opening at the bottom of the vessel. Air jet causes a stream of particle to rise rapidly through a hollowed central core or spout within the bed of solid. Particles after rising to a height above the surface of the surrounding packed bed or annulus, rain back as a fountain on to the annulus. Particles in the annulus region slowly move downwards and fluid from the spout leaks into the annulus and percolates through the moving packed bed and, to some extent inward as a loosely packed bed. Spout region is a centrally located dilute phase cocurrent upward transport region while in annulus hot air percolates countercurrently through the surrounding dense phase moving packed bed [2].

The spouted bed drying is particularly suitable for heat sensitive materials such as agricultural products or polymeric granules, since the continuous movement of particles [3] and short contact time permits the use of higher temperature gas than in non agitated driers, without the risk of thermal damage to the particles. Spouted bed helps to overcome the drawbacks such as non uniform heating in other heating applications. Relatively large air velocity also helps to maintain the constant product temperature and eliminate the possibility of product being overheated when product moisture content is low near the end of dying.

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Vertically injected air provides the pneumatic agitation for particle inside the drying bed. It also facilitates the heat and mass transfer due to the constantly renewed boundary layer at the particle surface. High input of heat carrier gas can be used to eliminate the lengthy drying time in spouted bed without degrading the quality of the material. Therefore spouted bed drying can be particularly useful to reduce the drying time since very high air temperatures (sometimes over 100°C) are being used.

Much of the spouted bed drying research during the past five decades has been carried out with assorted type of bio mass particles such as saw dust[4], paddy[5][6], barley, millet[7], soybean[8], corn[9] and etc. However conventional spouted bed dryers have some limitations such as higher pressure drop compared to the fluidized bed dryers and problem encountered in scaling up. In order to scale up, the draft tubes are inserted to separate the zones between spout region and the annulus region. Then more stable solid circulation and higher maximum spoutable height and low operating pressure drop can be achieved. Good quality products with homogeneous moisture content and temperature can be achieved using a spouted bed dryer[10]. Oliveira and Rocha (2007) used an intermittent drying spouted bed instead of using batch or continuous driven spouted bed, to reduce the cost in addition to maintain good product quality as the most grains become fragile in a fluidized bed or spouted bed dryer due to their exposure to severe attrition condition.

In spite of many advantages, thermal efficiency of the spouted bed dryers is still very low in industrial applications. However Wetchacama et al. (1999) has recycled the exhaust gas from the spouted bed dryers and recover heat in order to increase the drying process. Despite the fact that hydrodynamics and drying characteristics of spouted bed have been studied by many researchers, less attention has been paid to analyze the product quality after the drying process and to reduce energy consumption. Therefore Wetchacama et al. (1999) has analyzed the paddy quality in terms of rice whiteness and head rice yield.

Among many types of spices black pepper (Piper nigrum) is the most widely used spice all over the world. After harvesting usually raw pepper should be dried below 8-15% dry basis moisture level to stop the growth of fungus and to enhance the shelf life. If the moisture content is above the safe storage level, weight loss can be taken placed due to shrinkage or driven off of moisture. Therefore drying stage in black pepper is the most important factor determining suitability for storage, transport, milling and other processes because moisture content influences the trading price. Objective of this research is to study the possibility of using spouted bed technique for black pepper drying.

II. Materials and Methods

Black pepper was purchased from Jayantha Agro-chemicals in Galle, Sri Lanka and tempered to a moisture content around 70% dry basis by adding predetermined amount of distilled water. Seeds were then mixed daily and kept at a temperature of 2-5°C in a refrigerator for approximately 7 days to allow for moisture equilibrium within the seed and to avoid spoilage. Required amount of pepper was taken out of the refrigerator one hour before the experiment and allowed to reach the equilibrium to room temperature.

The schematic diagram of the experimental setup as shown in figure 1 consists of an air blower, an air heater, spouted bed column of 15 cm diameter, and a cyclone separator. Bottom of the conical section of spouted bed column is blocked by a perforated plate. The entire dryer is made of stainless steel. Spouted bed column is 1m high cylindrical column with a conical base. Spouted bed column is set either with or without draft tube. The draft tube is located centrally at the bottom of the conical base. Both type of draft tubes are made of stainless steel and porous draft tube is made of perforated plate of 2 mm perforation diameter. Table 1 summarizes the geometric factors of spouted bed and the draft tubes.

The bottom of the cone section of the spouted bed column is connected to the heater and blower while top of the column channels the exhaust to a reverse flow cyclone separator. The blower is operated by 3 hp motor while air heater has the capacity of 12 kW. The air flow rate was set at minimum spouting velocity of black pepper considering the energy and cost involved. Pressure measurements are carried by means of U tube water manometers while several openings are kept to insert the instruments used to measure air velocity and humidity. During experiment, inlet and outlet air temperatures were continuously monitored by k- type thermocouples and air humidity was measured by Thermo-Hygrometer Model GMK-920HT with an accuracy of ± 2%.

TABLE 1: GEOMETRIC FACTORS OF THE SPOUTED BED AND DRAFT TUBES

Spouted bed contactor		
Column diameter	D_c(m)	0.15
Base diameter	D_i(m)	0.05
Cone angle	γ	60
Height of conical section	H_c(m)	0.074
Height of cylindrical section	H_l(m)	1
Gas inlet diameter	D_o(m)	0.029, 0.035
Stagnant bed height	H_o(m)	0.10, 0.16
Draft tube		
Draft tube inside diameter	D_T(m)	0.029, 0.035, 0.048
Tube length	L_T(m)	0.19, 0.26
Entrainment height	L_H	0.03, 0.06

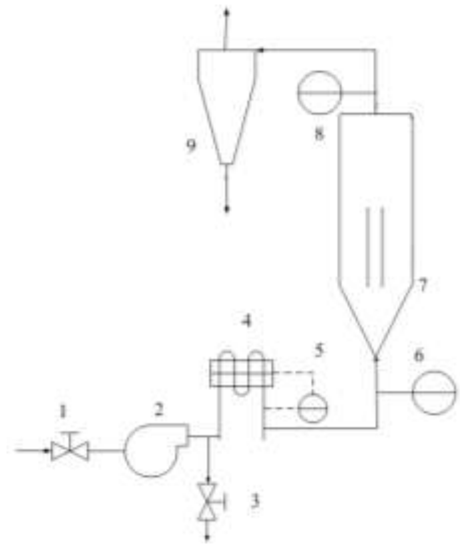

Figure 1: schematic diagram of the experiment set up

1, 3-Flow control valves 2- Blower
4, 5-Air heater with temperature control system
6, 8- Temperature indicators 7- Spouted bed column
9- Cyclone separator

In all experiments, fluctuations of temperature were within ±1°C. Air velocity at the inlet was measured by means of EXTECH CFM Thermo anemometer model 407113 with an accuracy of ±2 %.

Drying experiments were conducted in a conventional spouted bed dryer (without installing drat tube) and in a spouted bed dryer fitted with two different internal structures either non porous draft tube or porous draft tube. During drying experiments, pepper samples were collected in selected time intervals for determination of moisture content. The moisture content, X (% dry basis) of pepper samples were measured in accordance to ASAE method[11] and as per Equation(1).

$$X = \frac{W_w - W_d}{W_d} \times 100 \qquad (1)$$

Where W_w= weight of sample before being dried in oven
W_d= weight of sample after being dried in oven

III. Results and Discussion

Prior to the drying operation with black pepper, minimum spouting velocity was determined from the plot of pressure drop versus air velocity for two bed loadings of wet black pepper in spouted bed either with or without draft tubes. As indicated in Table 2, non porous drat tube fitted spouted bed has the lowest minimum spouting velocity followed by porous draft tube fitted system with respect to a specific bed height. Conventional spouted bed has the highest minimum spouting velocity. In all cases minimum spouting velocity increases with increasing stagnant bed height.

TABLE 2: MINIMUM SPOUTING VELOCITY

Spouted bed setting[a]	Stagnant bed height (m)	Minimum spouting velocity (m/s)	Flow rate (m^3/hr)
Conventional spouted bed	0.16	13.51	46.8
	0.10	9.21	31.9
Porous draft tube	0.16	10.57	36.6
	0.10	8.09	28.0
Non porous draft tube	0.16	9.41	32.6
	0.10	7.89	27.3

a. gas inlet diameter is 0.035 m.

A. ***Effect of drying temperature***

Effect of drying temperature was determined and results were analyzed. Figures 2 and 3 represent the drying kinetics of black pepper when dried without draft tubes at different drying temperatures. Fig 2 shows that increase in the drying temperature from 55 ˚C to 75 ˚C causes significant reduction of drying time from 100 minutes to 70 minutes confirming that the total drying time is reduced with the increase in the air temperature. According to figure 3 the highest drying rate was achieved when black pepper was dried at drying temperature of 75 ◦C.

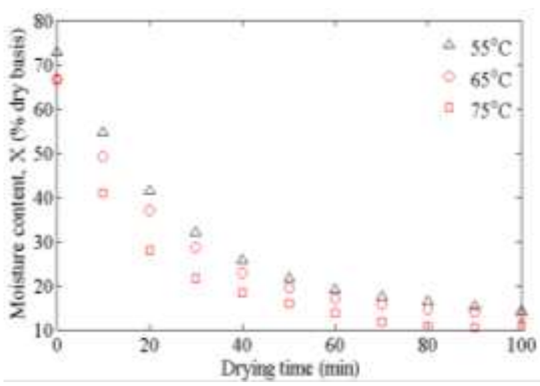

Figure 2: Moisture content (% dry basis) versus drying time of black pepper when dried without draft tube at different drying temperatures. Experiment conditions: Do =0.035 m, Ho =0.16 m, and air flow of 13.51 m/s

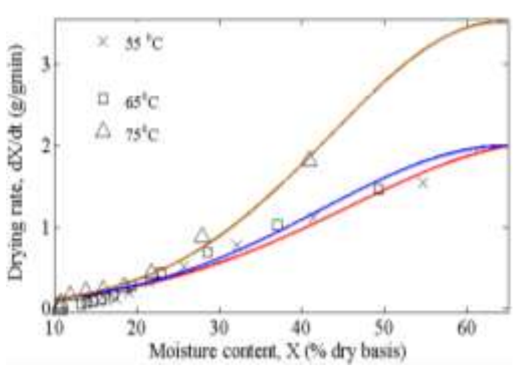

Figure 3: Drying rate, dX/dt versus moisture content (% dry basis) of black pepper when dried without draft tube at different drying temperatures. Experiment conditions: D_o =0.035 m, H_o = 0.16 m, and air flow of 13.51 m/s

Results show that moisture removal rates or drying rates are high at high hot air temperatures. Ng et al.(2006) also confirmed that drying temperature affects drying rate in many types of dryers including spouted bed dryer. Black pepper drying rate curves in spouted bed without draft tubes show only induction and falling rate periods. However constant rate period was not observed for the air temperatures applied in the present study. Although an increase in drying air temperature shortens the time of drying and consequently reduces the cost of the process, the quality of the final product may get affected. Therefore attention will be paid to analyze the quality of the final product in the future works.

B. ***Effect of draft tube***

Figures 4 and 5 show the effect of draft tube on drying kinetics of black pepper dried in spouted bed dryer. Fig 4 shows that drying time obtained from spouted bed with a non porous draft tube, porous draft tube and without draft tube are 125 minutes, 100 minutes and 70 minutes respectively. Installation of both types of draft tubes in the spouted bed dryer reduces the minimum spouting velocity of black pepper compared to that of conventional spouted bed dryer as shown in the Table 2.

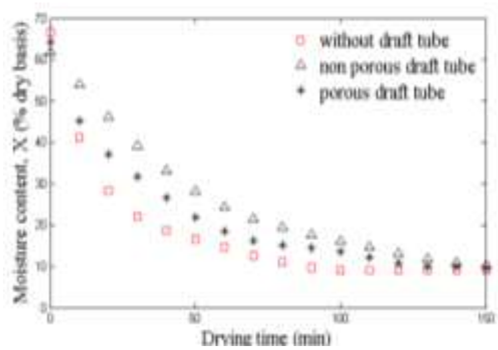

Figure 4: Moisture content (% dry basis) versus drying time of black pepper when dried with porous draft tube (air flow 10.57 m/s) or non porous draft tube (air flow 9.41 m/s) or without out draft tube (air flow 13.51 m/s). Experiment conditions: drying temperature = 75◦ C, D_o =0.035 m, H_o = 0.16 m, D_T= 0.035m, L_H = 0.06 m, L_T= 0.26 m

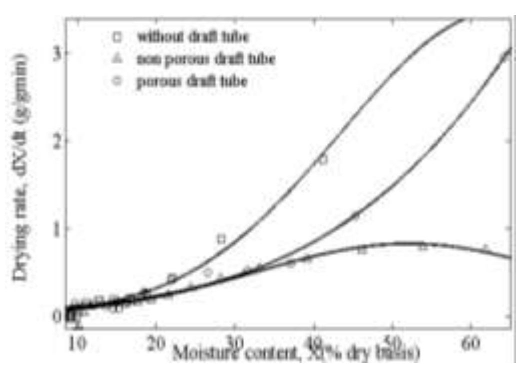

Figure 5: Drying rate, dX/dt versus moisture content (% dry basis) of black pepper when dried with porous draft tube (air flow 10.57 m/s) or non porous draft tube (air flow 9.41 m/s) or without out draft tube (air flow 13.51 m/s). Experiment conditions: drying temperature = 75◦ C, D_o =0.035 m, H_o = 0.16 m, D_T= 0.035m, L_H = 0.06 m, L_T= 0.26 m

Hence the gas flow rate corresponding to the minimum spouting conditions is low for the non porous draft tube. However considering the drying process, non porous draft tube fitted system performs poorly due to gas by passing through the spout without percolating to the annulus region.

All the drying rate curves are characterized by induction rate followed by a falling rate periods as mentioned in previous section. According to figure 5 conventional spouted bed experiences the highest drying rate followed by porous drat tube fitted system while non porous draft tube fitted spouted bed has the lowest drying rate. Solid particles are less exposed to the hot air in the annular region of the spouted bed with draft tubes and hence show lower drying rates compared to the conventional spouted bed dryers.

Use of porous draft tube increases the heat transfer rate compared to non porous draft tube since the porous draft tube has a higher annular airflow than that of non porous draft tube. Therefore spouted bed with porous draft tube offers improved performance as it reduces the flow rate and operating pressure drop, while increasing the drying rate.

C. *Effect of diameter of draft tube*

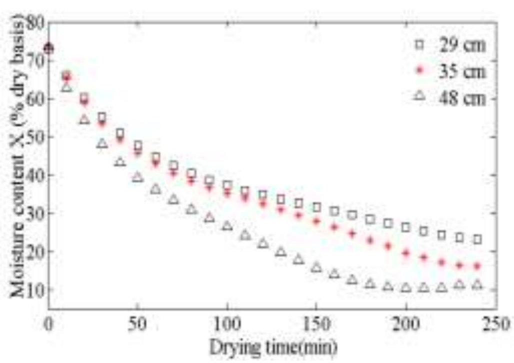

Figure 6: Moisture content (% dry basis) versus drying time of black pepper when dried with non porous draft tube having different values of drat tube diameters. Experiment conditions: drying temperature = 75˚C, D_o =0.029 m, H_o = 0.16 m, L_H = 0.03 m, L_T= 0.19 m

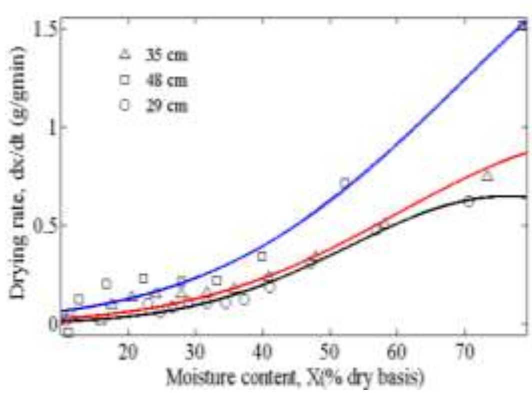

Figure 7: Drying rate, dX/dt versus moisture content (% dry basis) of black pepper when dried with non porous draft tube having different values of drat tube diameters. Experiment conditions: drying temperature = 75˚C, D_o =0.029 m, H_o = 0.16 m, L_H = 0.03 m, L_T= 0.19 m

Non porous draft tubes having different values of diameter were used to analyze the effect of diameter of draft tube on drying kinetics of black pepper. Other parameters of draft tube such as entrainment height, length of tube were kept constant. Figures 6 and 7 show the drying kinetics of pepper dried in non porous draft tube fitted spouted bed dryer. When diameter of the draft tube was increased, drying time was decreased and rate of moisture removal was increased. The amount of pepper seeds that can enter into the spout region is higher in larger diameter draft tube than that of smaller diameter draft tube, and hence intensive heating takes place inside the spout and therefore drying time decreases.

D. *Effect of bed height*

Figs 8, 9, 10 and 11 show the effect of bed height on the drying kinetics of black pepper in a spouted bed dryer either with or without draft tubes. Figure 11 indicate that moisture removal rate of 16 cm bed height is lower than that of 10 cm bed height in all conventional and drat tube fitted dryer settings.

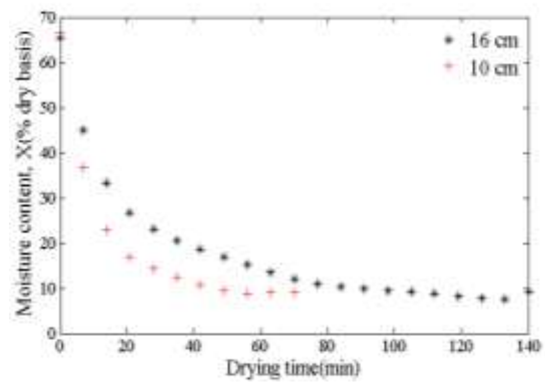

Figure 8: Moisture content (% dry basis) versus drying time of black pepper when dried without draft tube at different stagnant bed heights. Experiment conditions: Drying temperature = 75 ˚C, D_o =0.035 m

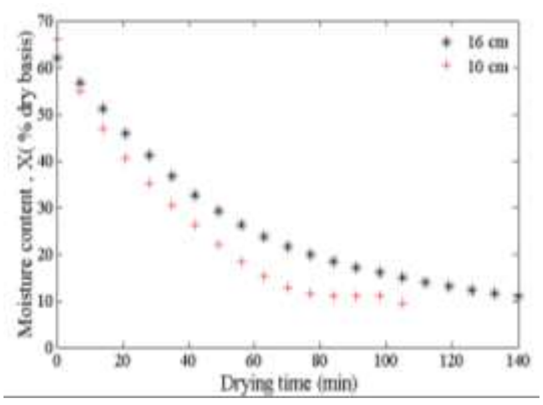

Figure 9: Moisture content (% dry basis) versus drying time of black pepper when dried with non porous draft tube at different stagnant bed heights. Experiment conditions: Drying temperature = 75˚C, D_o =0.035 m, D_T=0.035m, L_H = 0.06 m, L_T= 0.26 m

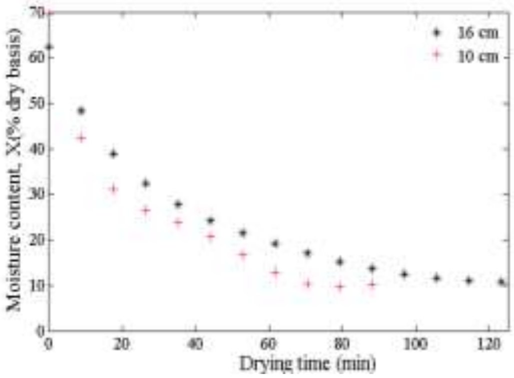

Figure 10: Moisture content (% dry basis) versus drying time of black pepper when dried with porous draft tube at different stagnant bed heights. Experiment conditions: Drying temperature = 75°C, D_o =0.035 m, D_T= 0.035m, L_H = 0.06 m, L_T= 0.26 m

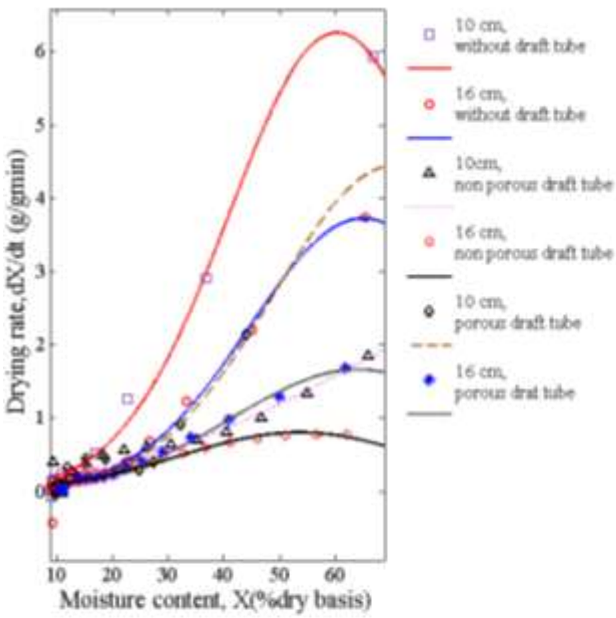

Figure 11: Drying rate, dX/dt versus moisture content (% dry basis) of black pepper when dried with non porous or porous draft tube or without draft tube at different stagnant bed heights. Experiment conditions: Drying temperature=75°C, D_o =0.035 m, D_T= 0.035m, L_H = 0.06 m, L_T= 0.26 m

Figures 8 to 10 shows that drying time required for a given moisture reduction increases with the bed height for all cases under investigations. For example in the conventional dryer the time required to reach a moisture content of 12% dry basis are 30 min and 70 min in the 10 cm bed and 16 cm bed respectively. Similarly drying time of spouted bed with non porous draft tube is 125 min for 16 cm bed height while 70 min in the 10 cm bed height. Deep beds require longer drying time and more energy for moisture removal than those of shallow bed. In spouted bed dryers, intensive heating and evaporation takes place in the spout region while particles are tempered in the annulus region Since deep beds have longer residence time in the annulus region, moisture removal rate is reduced than those of shallow beds which have shorter residence time in the annulus[12].

IV. Conclusion

Spouted bed dryer with or without draft tubes is suitable for black pepper drying due to its simple design and good performance. Fast rate of drying of black pepper is achieved at a moderately high air temperature and low bed height. The installation of draft tube reduces the flow rate of air required for spouting. In all cases under study drying took place in the induction and falling rate period. The drying time decreases considerably with the increase of air temperature. The rate at which black pepper is dried is dependent on air temperature, bed height, type of draft tube and diameter of draft tube.

Acknowledgment

The authors are grateful to the HETC Project of Ministry of Higher Education- Sri Lanka for financial support and to Mega Heaters(Pvt) Ltd. for patiently and carefully constructing the experimental set up.

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