

## Effects of Coffee Form and Distributor Hole Angle on The Fluidization Behavior and Specific Energy Consumption in The Fluidized Bed Machine

Thatchapol Chungcharoen<sup>1</sup>, Warunee Limmun<sup>1</sup>, Sansanee Sansiribhan<sup>2,\*</sup>

<sup>1</sup> Engineering Department, King Mongkut's Institute of Technology Ladkrabang, Prince of Chumphon Campus, Chumphon, Thailand

<sup>2</sup> Applied Physics Program, Faculty of Science and Technology, Suan Sunandha Rajabhat University, Bangkok, 10300, Thailand

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### ABSTRACT

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The fluidized bed technique was applied to use with the Robusta coffee in this research. fluidization behavior and specific energy consumption were investigated under various coffee forms and distributor hole angles. Moreover, the minimum fluidization velocity ( $V_{mf}$ ) was also determined. Experiments are carried out in a sample bed height of 5 cm with ambient air. In this study, two coffee forms (Ripe coffee cherries; RCC and parchment coffee; PC) and three distributor hole angles ( $45^\circ$ ,  $60^\circ$  and  $90^\circ$ ) are examined. The experimental result shown that the fluidization behavior is influenced by coffee form and distributor hole angle. The RCC and distributor hole angle of  $60^\circ$  provided the low pressure drop throughout the superficial air velocity. The low values of  $V_{mf}$  and SEC were also achieved in the RCC and distributor hole angle of  $60^\circ$ .

## 1. Introduction

Coffee is one of most popular agricultural crops in Chumphon province especially Robusta coffee which represents around 80% of the total Thailand coffee production [1]. Normally, the Robusta coffee is produced to green coffee bean by either dry or wet processing [2, 3]. The drying is one of important steps in those processing. It is done by placing the ripe coffee cherries (in case of dry processing) or the parchment coffees (in case of wet processing) in the sun until the moisture content reached 11-12% wet basis [4]. This drying method provides the long drying time because it depends on the weather conditions. Moreover, it can't control the uniform moisture content during drying. Therefore, the new method for drying is necessarily determined.

In recent years, the fluidized bed drying technique have been applied to dry many agricultural crops [5-7]. This technique provides the good mixing between material and drying medium, leading to rapidly decrease the moisture content and resulting in the shorter drying time [8]. Moreover, it provides the uniform moisture content during drying. By this drying method, it would be more effective to reduce the moisture content of coffee. The flow characteristic is one of the most important concerns in fluid and there are some studies on the flow characteristic [9, 10]. For fluidized

\* Corresponding author.

E-mail address: [sansanee.sa@ssru.ac.th](mailto:sansanee.sa@ssru.ac.th)

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bed drying technique, fluidization behavior is focused because it is used for investigation in the minimum fluidization velocity ( $U_{mf}$ ) which directly effects the decrease of moisture content. There are many factors affecting the  $U_{mf}$  and several investigations have been done in the  $U_{mf}$ . Escudero and Heindel [11] studied the  $U_{mf}$  in a 3D fluidized bed modified with an acoustic field. Their results revealed that as the frequency and sound pressure level increased, the value of  $U_{mf}$  decreased. Khan *et al.*, [12] studied the effect of initial static bed height and liquid superficial velocity on the  $U_{mf}$  value and pressure drop for the bed of semolina particles in liquid-solid fluidization. The results showed that there was no significant change in the  $U_{mf}$  with different initial static bed height. The increase of liquid superficial velocity above the  $U_{mf}$  led the particles vigorous motion and resulted in the better mixing in the fluidization. Sau *et al.*, [13] studied the  $U_{mf}$  and the pressure drop across the bed using a gas–solid conical tapered fluidized bed. The results showed that the  $U_{mf}$  value was independent of bed height for this type of conical tapered fluidized bed. Zhang *et al.*, [14] analyzed the effect of mechanical vibration on the fluidization characteristics of fly ash in a fluidized. The results showed that the mechanical vibration provided the decrease of  $U_{mf}$ .

The coffee form and distributor hole angle are two interested factors which affected the  $U_{mf}$  and it has not been reported about theirs factors effected on the  $U_{mf}$ . Therefore, the main objective of this research was to investigate the effects of coffee form and distributor hole angle on the fluidization behavior in the fluidized bed dryer. Moreover, the specific energy consumption was also determined. The result of this research would be useful information for drying the coffee using the fluidized bed dryer.

## 2. Methodology

### 2.1 Sample Preparation

Ripe coffee cherries (RCC) as shown in Figure 1(a) were purchased from the Small and Medium Enterprises (SMEs) in Chumphon province. They were cleaned to get rid of foreign materials before testing. In term of parchment coffee (PC), the RCC was dehusked to the PC as Shown in Figure 1(b) before testing. The initial moisture contents of RCC and PC were found to be 60% (d.b.).



**Fig. 1.** Coffee form (a) Ripe coffee cherries (RCC) (b) parchment coffee (PC)

### 2.2 Experimental Procedure

The experiments were conducted in an air flow fluidized bed machine as shown in Figure 2. The cylindrical fluidized bed chamber was fabricated with acrylic of 20 cm diameter and 100 cm height. A blower of 2 hp is used to generate the ambience air which entered into the chamber from bottom through distributor. As shown in Figure 3, there are three patterns of distributor based on distributor

hole angle such as 45°, 60° and 90°. Inverter is used to control the flow of air and manometer is used to measure the pressure drop across the bed.

In each experiment, the samples (bed height = 5 cm), both RCC and PC, were placed into a cylindrical fluidized bed chamber and the blower was started to fill the ambience air at various superficial air velocities. The pressure drop was observed in manometer. Moreover, the total amount of energy consumed during testing was also noted.

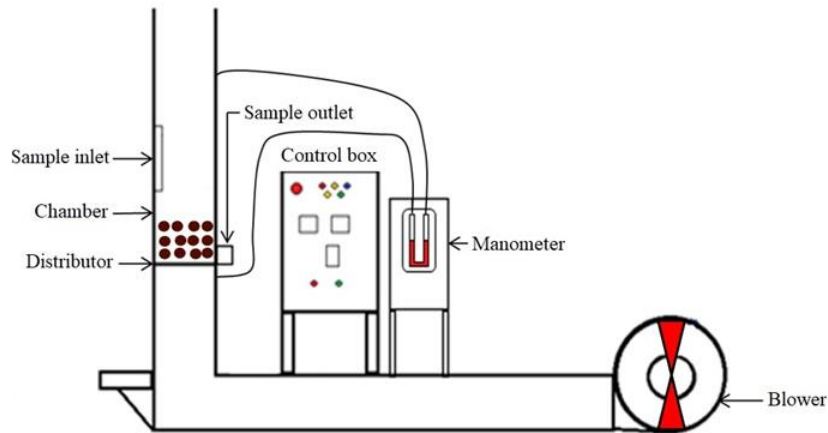


Fig. 2. Air flow fluidized bed machine

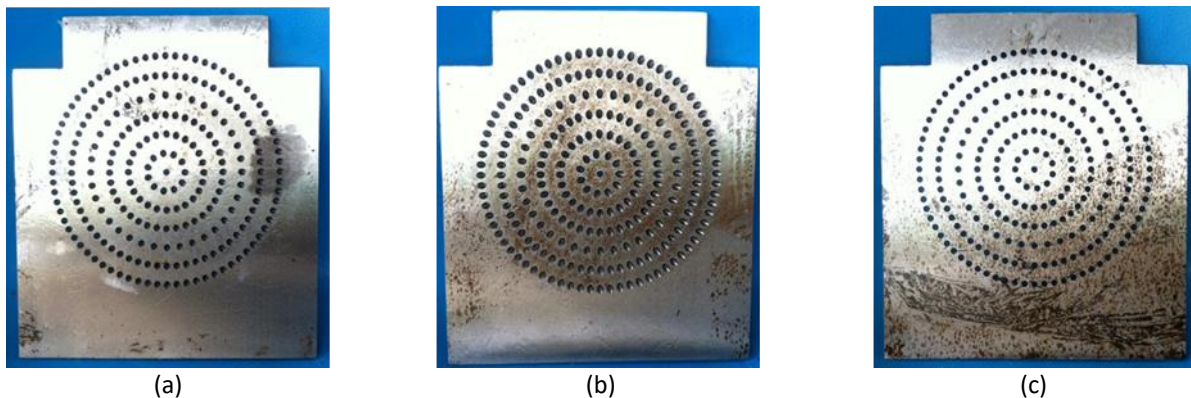


Fig. 3. patterns of distributor with different hole angle (a) hole angle of 45° (b) hole angle of 60° (c) hole angle of 90°

The pressure drop and specific energy consumption (SEC) value were calculated as shown in Eq. (1) and Eq. (2), respectively.

$$\Delta P = \rho g \Delta h \quad (1)$$

where  $\Delta P$  is pressure drop across the bed (Pa),  $\rho$  is fluid density ( $\text{kg/m}^3$ ),  $g$  is acceleration due to gravity ( $\text{m/s}^2$ ) and  $\Delta h$  is different height of liquid in manometer (m).

$$SEC = \frac{3.6P}{\text{Mass of sample}} \quad (2)$$

where  $SEC$  is specific energy consumption ( $\text{kWh/kg}$ ) and  $P$  is the total amount of energy consumed during testing ( $\text{kWh}$ ).

### 3. Results

#### 3.1 Bed Sample Properties

The properties of RCC and PC were showed in Table 1. The experimental result shown that there are significantly different for all properties between RCC and PC. The PC provided the lower porosity and equivalent diameter than RCC while the weight of PC was higher than that of RCC. The different properties between RCC and PC may be due to the shape of sample [15, 16]. The shape of PC was quite oval, whereas that of PCC was round, thus allowing the sample of PC to be tightly pack and resulting in the lower porosity and higher weight.

**Table 1**

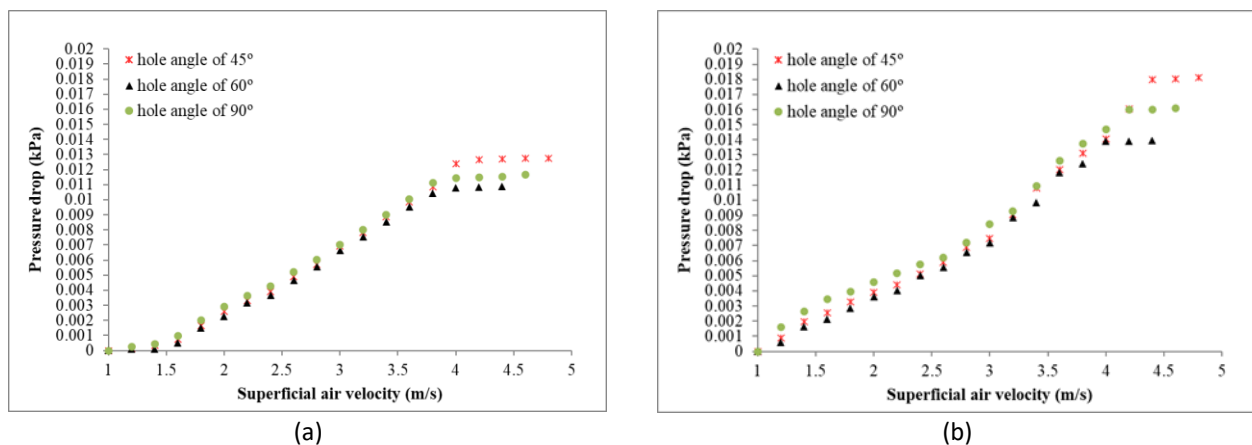
The properties of RCC and PC

| Coffee form | Weight (bed height of 5 cm)<br>(kg) | Porosity               | Equivalent diameter<br>(mm) |
|-------------|-------------------------------------|------------------------|-----------------------------|
| RCC         | 0.97±0.00 <sup>b</sup>              | 0.65±0.03 <sup>a</sup> | 12.5±0.23 <sup>a</sup>      |
| PC          | 0.99±0.01 <sup>a</sup>              | 0.55±0.29 <sup>b</sup> | 5.11±0.35 <sup>b</sup>      |

<sup>a, b</sup> Means in the same column with different superscripts are significantly difference ( $p < 0.05$ )

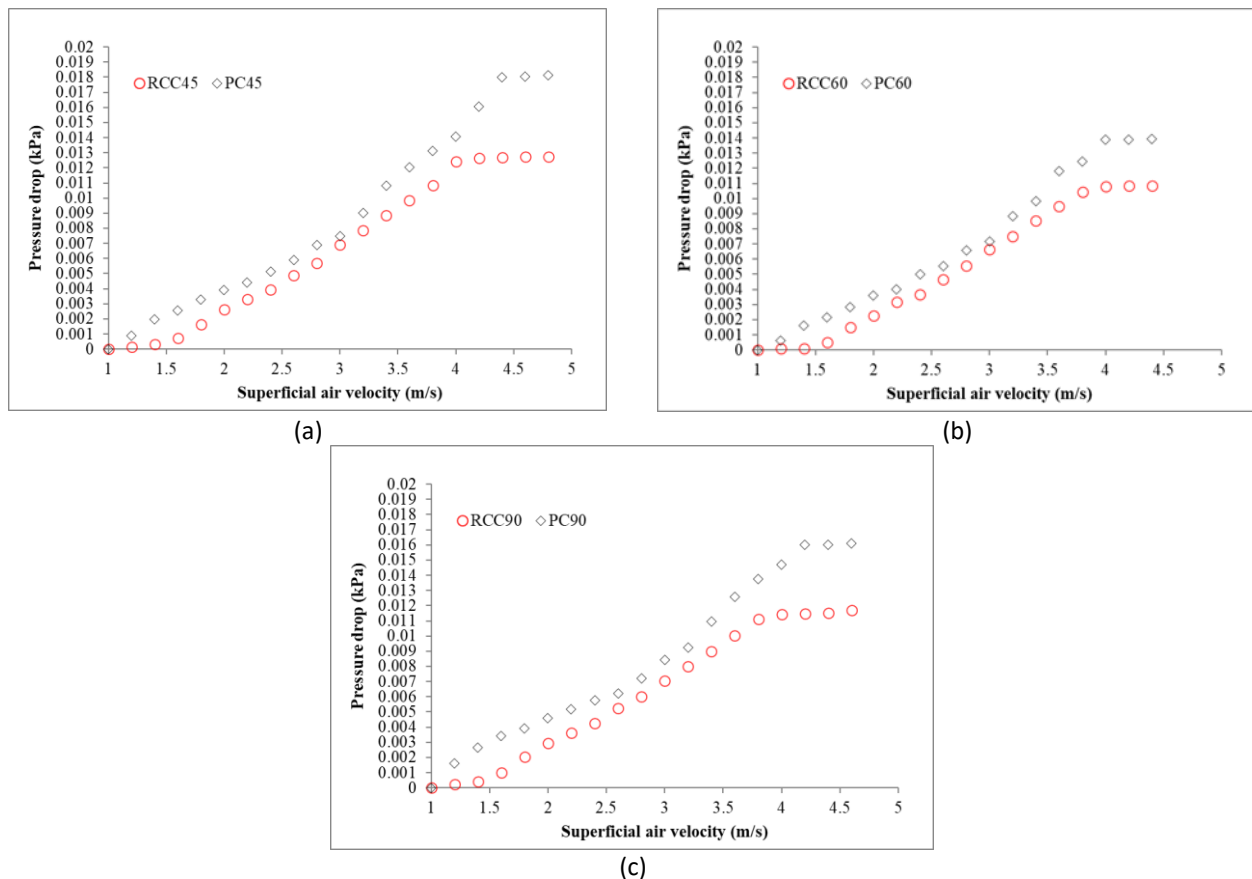
#### 3.2 Fluidization Behavior

Figure 4 shows the fluidization behavior of sample at various distributor hole angles. The changes of pressure drop for both RCC and PC had a similar pattern. The pressure drop was rapidly increased with increasing at the early superficial air velocity period (from 0 to 4 m/s approximately). This is because bed of sample still fixed. When the superficial air velocity was more increased, the pressure drop became constant. This indicated that the fluidizing was achieved [12, 17, 18]. When comparing among the distributor hole angle, the pressure drop of distributor hole angle of 60° was slightly lower than another distributor hole angle for both RCC and PC. This may because the distributor hole angle of 60° provided the air to easily pass through the bed of sample.



**Fig. 4.** Fluidization behavior of sample at various distributor hole angles (a) RCC (b) PC

The comparisons of fluidization behavior between RCC and PC at the same distributor hole angle were showed in Figure 5. The pressure drop of PC was higher than that of RCC for all distributor hole angle due to the cohesiveness of sample. The PC was the sticky particle, leading to more pressure drop than RCC.



**Fig. 5.** Comparison of fluidization behavior between RCC and PC (a) distributor hole angle of 45° (b) distributor hole angle of 60° (c) distributor hole angle of 90°

### 3.3 Minimum Fluidization Velocity ( $V_{mf}$ ) and Specific Energy Consumption (SEC)

The minimum fluidization velocity ( $V_{mf}$ ) and specific energy consumption (SEC) of RCC and PC at various distributor hole angles were shown in Table 2. The experimental result shown that the coffee form and distributor hole angle affected the  $V_{mf}$  and SEC values. The RCC provided the lower  $V_{mf}$  than PC at every distributor hole angle. Moreover, the  $V_{mf}$  with distributor hole angle of 60° was lowest for both RCC and PC. These led the lower SEC value in the RCC than PC and the lowest SEC value in distributor hole angle of 60° when comparing with another distributor hole angle. The effect of distributor on the  $V_{mf}$  agrees with the results reported by Hilal *et al.*, [19], who noted that the value of the minimum fluidization velocity was increased with decreasing perforated plate distributor hole pitch.

**Table 2**  
 The  $V_{mf}$  and SEC values of RCC and PC at various distributor hole angles

| Coffee form | Distributor hole angle (Degree) | Minimum fluidization velocity (m/s) | SEC (kWh/kg)           |
|-------------|---------------------------------|-------------------------------------|------------------------|
| RCC         | 45                              | 4.2±0.0 <sup>a</sup>                | 6.73±0.14 <sup>a</sup> |
|             | 60                              | 3.9±0.1 <sup>b</sup>                | 5.64±0.52 <sup>b</sup> |
|             | 90                              | 4.1±0.1 <sup>a</sup>                | 6.75±0.77 <sup>a</sup> |
| PC          | 45                              | 4.3±0.1 <sup>a</sup>                | 6.97±0.09 <sup>a</sup> |
|             | 60                              | 4.0±0.0 <sup>b</sup>                | 5.81±0.24 <sup>b</sup> |
|             | 90                              | 4.2±0.1 <sup>a</sup>                | 7.15±0.20 <sup>a</sup> |

<sup>a, b</sup> Means in the same column with different superscripts are significantly difference ( $p < 0.05$ )

#### 4. Conclusions

In this study, the differences of coffee form (ripe coffee cherries: RCC and parchment coffee: PC) and distributor hole angle (45°, 60° and 90°) were performed to investigate the fluidization behavior and Specific Energy Consumption (SEC) in the Fluidized Bed Machine. The experimental results showed that coffee form and distributor hole angle are directly affected the fluidization behavior and SEC value. The RCC provided the lower pressure drop than PC for all distributor hole angle, leading to lower minimum fluidization velocity ( $V_{mf}$ ) and SEC value. In term of distributor hole angle, the pressure drop was lowest for both RCC and PC when using the distributor hole angle of 60°. This distributor hole angle also provided the lowest in  $V_{mf}$  and SEC values. These results can be used for applying the coffee drying using the fluidized bed dryer in the coffee industry and Small and Medium Enterprises (SMEs).

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