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Analysis on the Performance of Designed Fluidized Bed Dryer for Drying Coffee Beans

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ABSTRACT

Drying coffee beans is an important role in the process of making coffee. Most coffee producers dry their coffee beans under the natural sun, but it was found to be time-consuming and depended on the weather conditions. Fluidized bed dryer is found to be the most recent method to dry the coffee beans. However, not many reported on the performance of fluidized bed dryer in coffee drying. In the present research, the quality of the drying process using fluidized bed dryer was investigated by varying the streamline pattern and temperature distribution in the drying chamber. The result was compared with a different temperature and velocity applied. The simulation in ANSYS was conducted with three different velocities of 10 m/s, 20 m/s and 30 m/s with air temperature of 60 °C, 90 °C and 120 °C. The temperature supply was from the inside of the pipe to the end of the drying chamber. The streamline and the temperature distribution were absorbed between the difference of temperature and the velocity difference. The computational analysis of the simulation showed that the increase in velocity resulted in a temperature rise from 46.72°C to 49.04°C within the drying chamber for constant inlet temperature of 60 °C, and on the other hand the velocity in the drying chamber remains constant at average of 3.22 m/s for inlet velocity of 10 m/s despite the increase in temperature.

1. Introduction

Coffee is a brewed beverage made from roasted coffee beans, which are the seeds of berries belonging to the Coffee species. Coffee berries are collected, processed, and dried when their color changes from green to bright red, indicating ripeness. Dried coffee beans are roasted to a variety of temperatures to achieve the desired flavor. Coffee is made by grinding roasted beans and brewing them in water that is near boiling. The most widely grown coffee bean varieties are coffee arabica and Coffee Robusta. Brazil is the world's largest coffee producer, with 60.2 million sacks made in 2018, with Coffee arabica accounting for 74% and Coffee Canephora for 26% [1]. Coffee beans are

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harvest from the coffee tree and dried in one of three ways before being roasted: dry, wet, or semidry fermentation. Depending on the climate condition, to achieve 12.5 percent of moisture content of coffee beans, it may take up to 4 weeks to dry the cherries. The coffee beans need to be dry before the roasting process begin.

Coffee is a beverage with a long and prosperous past. The practice of brewing beverages from roasted coffee beans is believed to have originated in the Middle East and Africa centuries ago. Green coffee beans are the seeds that have not matured. They are referred to as coffee cherries and have a beany, grassy fragrance. Prior to roasting the coffee beans, they are processed and dried. The humidity content of a coffee bean ranges between 8% and 12%. The coffee beans must be totally dry before roasting. By extracting food moisture content, the hot air-drying process is used to regulate enzymatic reactions and microbiological deterioration and it is also widely used in the industry especially in food industry. A common method of food preservation is drying, which involves simultaneous heat and mass transfer through the porous food structure [2]. Other than a common method for food preservation, it is also among the most effective food processing methods, with applications ranging from low-humidity agricultural crops such as rice, corn, and wheat to medium-humidity products such as pasta, tea, and coffee, and high-humidity products such as milk, fruit, and vegetables [3]. The most common food preservation is drying which is one of the oldest methods of food preservation. It is crucial to obtained 12% of moisture content which helps to enhance the flavor and aroma profiles of the coffee beans before starting the roasting process. So, it is important to complete the drying process of the coffee beans. To begin with, the cherries are dried immediately and hulled until the moisture content is obtained [4]. To obtain a green coffee, the coffee cherry usually goes through a drying process which is dry or wet process. The drying is usually done on the clean, dry mats or floor under the sun. It is very common for the coffee producers to dry their coffee beans under the natural sun, but this method has come with disadvantage which is it consume much time during the operation, and it is also depends on the weather conditions. Besides, it is also requiring a lot of labor to perform the process. Previously, sun dried green coffee was thought to be the highest quality, but as the coffee beans become more popular and increase in demand, the sun drying method cannot keep up with the increase of production as this method also are not consistent as they depend on the climate conditions. Other than the traditional way of drying coffee beans, drying coffee beans using the fluidized beds is also a method of drying coffee cherries.

1.1 Literature Review

Drying food is one of the oldest methods of preserving food from spoilage. As technology advances, so does the technique for drying food. One of the technologies is Microwave Drying and Combined Microwave Drying. A microwave oven is a type of electric oven that uses electromagnetic radiation in the microwave frequency range to heat and cook food. Microwave drying focus on the heating process inside the material and moving moisture through it which increase the efficiency of the drying while maintaining a high internal vapor pressure [5]. On the other hand, the disadvantages of microwave drying if the temperature is elevated excessively will cause inconsistent heating, a shallow penetration depth, and the possibility of causing texture damage to the product. Other than that, Infrared Drying and Combine Infrared Drying is also a method to preserve food from spoilage. This method of drying is well suited for a material with thin layer and a large surface area that is exposed to radiation. Infrared drying is a result of the temperature difference between the emitted liquid as well as the ambient air stream. It produces a small stage of pressure between the internal and external of the granule which serves as a powerful driving force for moisture extraction.

The next method is by using power ultrasound. A sound is a signal that travels through a medium of transmission, such as a gas, liquid, or solid. When the particles are in the equilibrium state, they stay vibrate at their equilibrium position and whenever there is a mechanical wave interference, it disturbs the equilibrium state, which propagates through the medium. Finally, the mechanism reaches equilibrium, or a state that is unchanged. The frequencies that used generally between 20KHz and 40KHz for food dehydration [6]. Dehydrating porous materials with high-energy ultrasound can be extremely successful in processes that involve the treatment of heat-sensitive materials, such as food. As a result of the ultrasonic assisted hot-air drying process, lower temperatures or shorter treatment times are possible. Consequently, this method is capable of dehydrating food without affecting its primary characteristics or consistency. The maximum drying time reduction of approximately 79 percent can be achieve by combining ultrasound and microwave in convective drying. Next is in the food processing industry, spray-drying is usually used to convert solution into instant powder or solid. The process starts when the atomizer containing liquid stream is pumped to form extremely small droplets into the drying chamber. Spray drying was a commonly used in industrial method for processing dry powders with a low moisture content. Spray drying is a four-stage process that begins with the atomization of liquid feed into the spray chamber. The second step is the contact between the spray and the drying medium. Thirdly, the moisture in the substance is evaporated, and eventually, the dried product is removed from the air flow [7]. An experimental investigation of the gasification on coffee beans is conducted by using a semi-FzBR using steam and/or CO_2 gasification agent which stated that the complex thermochemical reaction influenced by the process's various parameters is required for the gasification process. One of the most critical criteria determining syngas quality and gasification output is reactor temperature. The gasification process requires temperatures above 700 °C to decrease tar production and convert the char left over from the pyrolysis step into syngas [8]. Solar drying is one of the oldest drying methods that utilizes solar radiation and energy. It has been used for food preservation since the beginning of time, but it has also been used to dry other useful materials such as cloths, building materials, and other objects [9]. Solar drying is not widely available at the moment. Solar dryers are usually small-capacity machines that are built empirically or semi-empirically rather than theoretically. The majority of solar dryers on the market are used to dry a variety of crops for personal use or small-scale industrial production.

2. Methodology

This experiment will go over the simulation evaluation methodology for drying coffee beans using a fluidized bed dryer. This simulation was meticulously planned to ensure that it was completed on time and met the project's objectives. Ansys software will be used to evaluate the constructed fluidized bed dryer. The simulation was used to investigate the performance of the fluidized bed dryer. As previously stated, the experiment is about to investigate the pattern of the air streamline and the temperature at the drying chamber, so the simulation can aid in the study and investigation of the fluidized bed dryer's performance.

2.1 Research Flowchart

Refer to the flowchart in Fig. 1, this study started from defining the problem statement and objective followed by preparing the literature review for the study. Next was the design concept of the fluidized bed dryer preparation in Solidworks and then the design was used in the ANSYS Software to find the heat distribution and streamline pattern of the fluidized bed. After the results were obtained, the fluidized bed dryer was analysed and discussed. Lastly, conclusion was made and some future recommendation was stated to improve the simulation for future study.

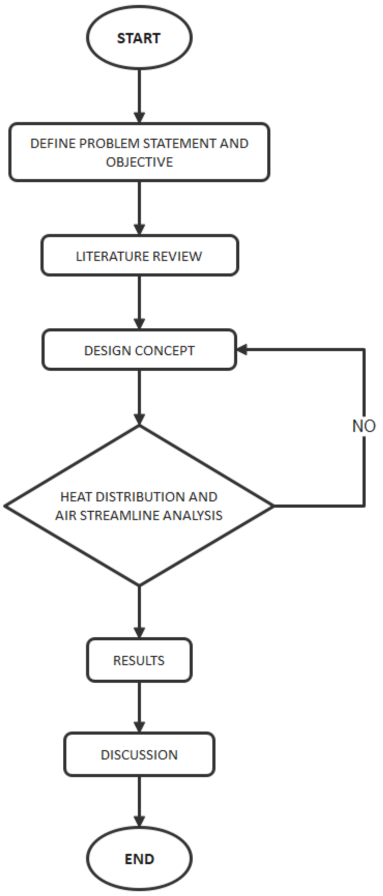


Fig. 1. Research flowchart

2.2 Fluidized Bed Dryer Specification

The simulation was performed on our own design that was fabricated using Solidwork. The dimension was chosen based on the simulation's suitability. It includes the drying chamber, distributor, air flow pipe from the heating chamber to the drying chamber, and a stand. The fluidized bed dryer is depicted in the Figure 2, and the specifications are listed in Table 1. Exploded view of the fluidized bed can be seen in Figure 3.

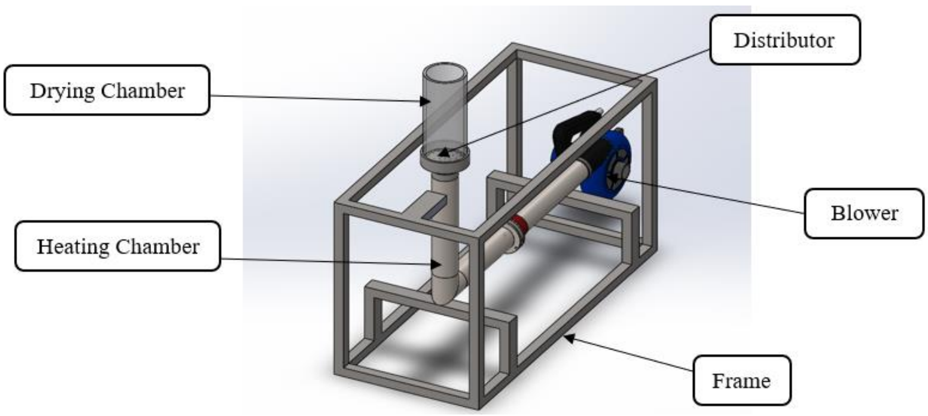


Fig. 2. Design of the fluidized bed

Table 1
Dimensions of the fluidized bed dryer

Parts	Dimensions
Drying chamber	Height: 200mm Outer diameter: 80mm Inner diameter: 70mm
Heating chamber	Height: 315mm Diameter: 49mm
Distributor	Diameter: 80mm Hole diameter: 3mm Thickness: 4mm
Frame	Length: 600mm Width: 300mm Height: 350mm

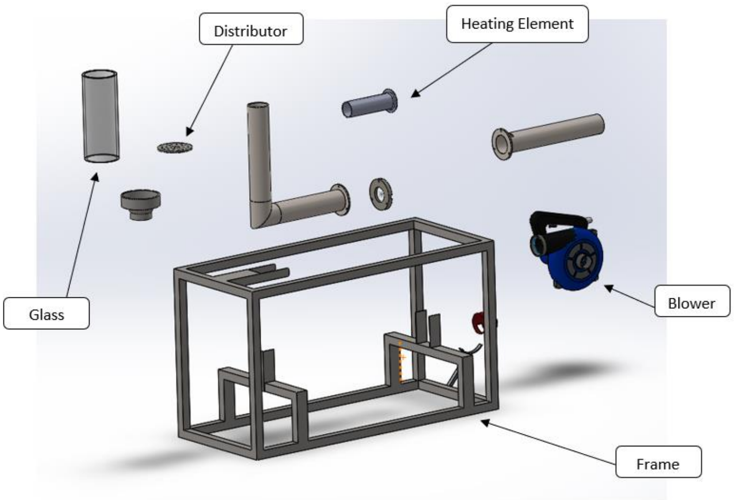


Fig. 3. Exploded view of the fluidized bed

2.2.1 Distributor

In this study, just one distributor as shown in Figure 4 was used in the simulation. The distributor's hole is shaped like a circle with a diameter of 3 mm for each hole. The distributor assisted in determining the outcome of the streamline pattern, as specified in the simulation experiment's goal. Then we will look at how the streamline changes as the air velocity changes [10]. The manipulated variables in this simulation are velocity and temperature.

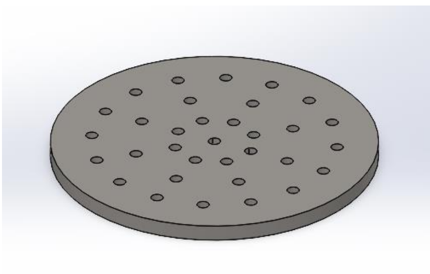


Fig. 4. Design of the distributor

2.3 Simulation Method

In this simulation experiment, the finite element calculation was carried out using the ANSYS programme. We can define our own characteristic for the finite element on the model that is suitable for the calculation in this programme. To improve measurement accuracy, the programme can change the grain size and smoothing of the grain.

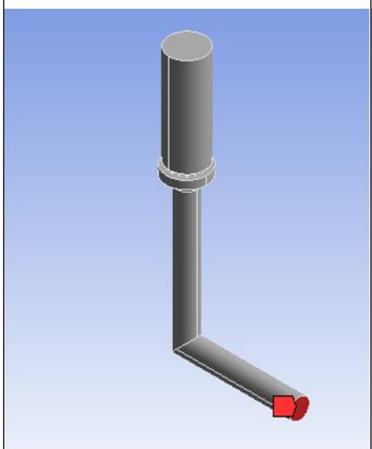
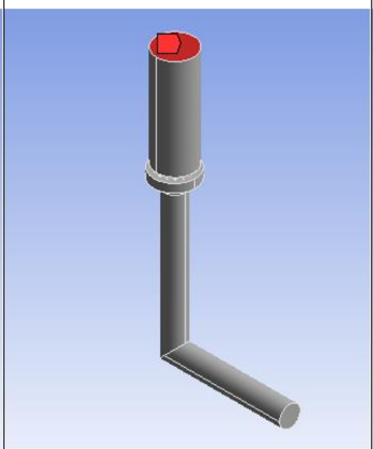
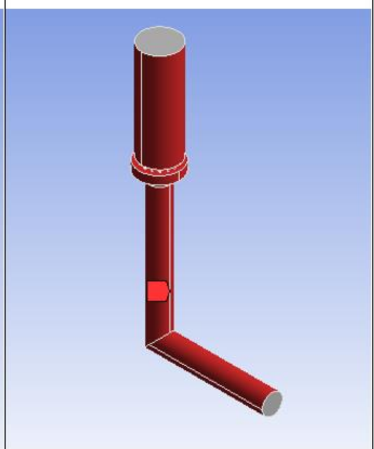
A simulation software will be used to evaluate the constructed fluidized bed dryer. The simulation was used to investigate the performance of the fluidized bed dryer. As previously stated, the experiment is about to investigate the pattern of the air streamline and the temperature at the drying chamber, so the simulation can aid in the study and investigation of the fluidized bed dryer's performance.

To complete the simulation for the air streamline and temperature, ANSYS software was used. The air streamline pattern and temperature will be measured and recorded. Because we have different air velocity, the end result will be a different pattern, streamline, and temperature. Three separate simulations will be run, each with a different temperature and a different velocity. The velocity will be set to 10 m/s, 20 m/s, and 30 m/s, and the temperature is set to 60°C, 90°C and 120°C with the procedure repeated for each fluidized bed dryer.

2.3.1 Detail procedure

i. The fluidized bed dryer was design by using SOLIDWORK.
ii. The distributor was design with hole is shaped like a circle with a diameter of 3 mm.
iii. The design of the fluidized bed dryer was imported to ANSYS software.
iv. In ANSYS, the volume of the fluidized bed dryer will be extract.
v. The extract volume will continue for finite element calculation and meshing.
vi. The part for the inlet, outlet and also the wall of the fluidized will be set (Table 2).

Table 2
Part of simulation

The Inlet Part	The Outlet Part	The Wall Part
		

vii. The pattern of the grain, the size of the grain, the quality, can be change at the mesh setup (Figure 5).

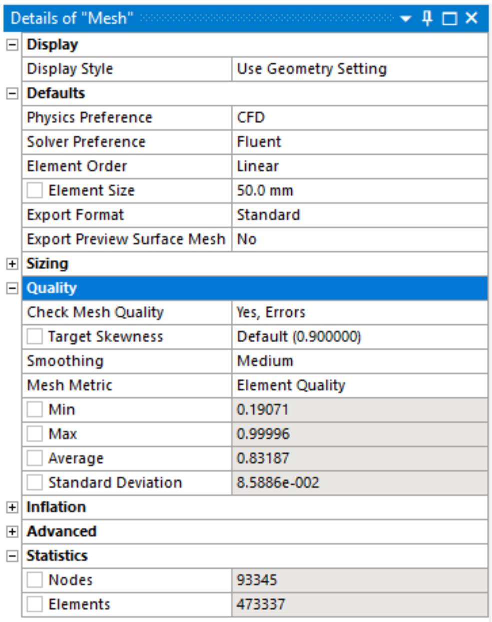


Fig. 5. Mesh setup

viii. The gravity was set at y-axis as -9.81 m/s^2

ix. Flow of the air was set to turbulent flow or k-omega (Figure 6).

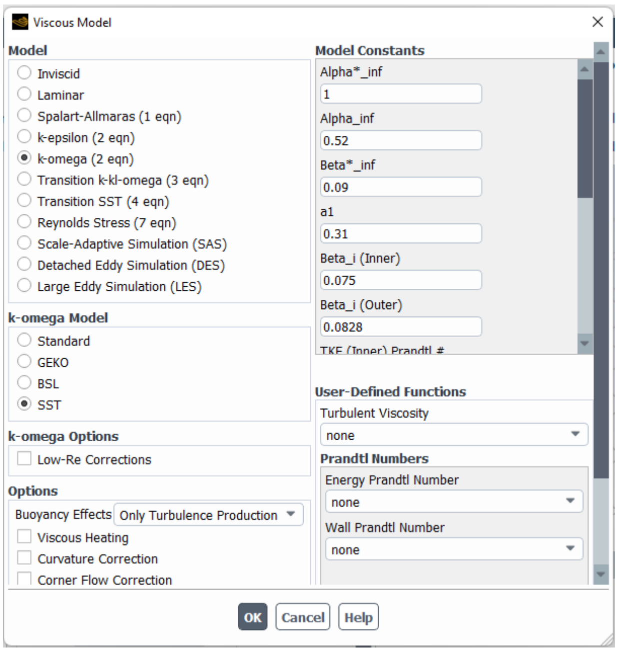
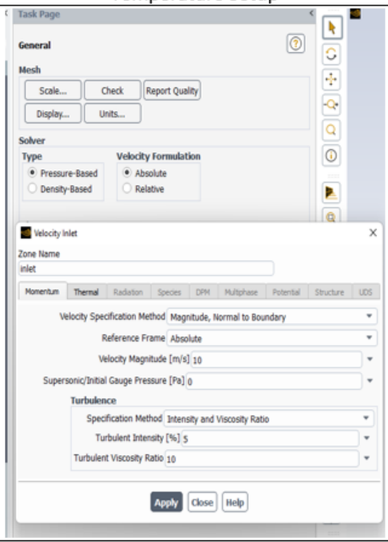


Fig. 6. Setup of the model of flow through in the fluidized bed dryer

x. Change the type of fluid at the material setup, from that it will give all the information about the fluid characteristic.

xi. The velocity and the temperature will be set (Table 3).

Table 3
Setup of temperature and velocity

Temperature Setup	Velocity Setup
	

xii. The initialization will set at the inlet part because the flow starts from the inlet.
xiii. The simulation was set for 400 iterations to make the result more precise.
xiv. After the calculation, the result will be shown and need to set for the temperature and the streamline.
xv. A XY Plane is drawn to get the reading of the temperature and velocity.
xvi. The experiment was conducted with three difference velocity.
xvii. The simulation for temperature 90°C and 120°C will be repeated same as the temperature 60°C by following the procedure.

3. Results

3.1 Data

Ansys software is used to analyse the heat distribution and the streamline pattern. The analysis should show whether the design of the fluidized bed dryer is efficient to be used in drying the coffee beans.

3.1.1 Data of the simulation

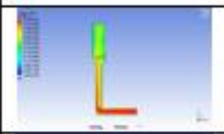
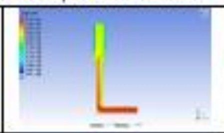
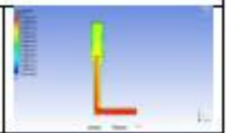
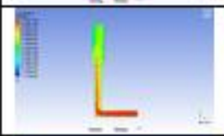
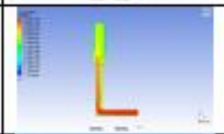
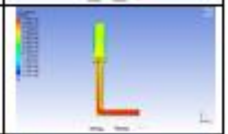
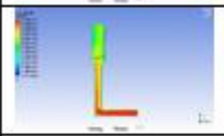
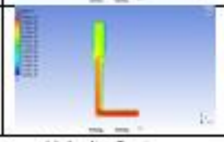
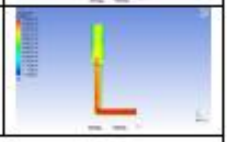
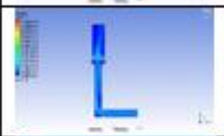
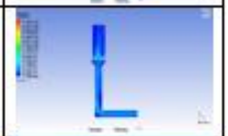
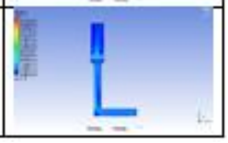
The Table 4 shows the data obtained from the simulation. The data conclude that as the inlet velocity increase, the average temperature at the outlet also increase. On the other hand, as the temperature increase at the inlet temperature, the average velocity at the outlet remains the same. Generally, heat transfer and phase changes occurred primarily during the drying process. The energy of water molecules and moisture diffusivity were altered by temperature, which may explain why the moisture evaporation rate is faster as the temperature increase [11].

Table 4
Simulation data

Velocity	Temperature [°C]	Outlet Average Temperature [°C]	Outlet Average Velocity [m/s]	Volume Average Temperature [°C]	Volume Average Velocity [m/s]
10	60	46.72	3.20	51.13	6.88
20	60	48.01	6.35	52.28	13.71
30	60	49.04	9.53	52.80	20.87
10	90	62.20	3.23	72.04	7.00
20	90	66.02	6.35	74.57	13.71
30	90	68.09	9.53	75.61	20.87
10	120	78.33	3.23	93.07	7.00
20	120	84.04	6.35	96.85	13.71
30	120	87.13	9.53	98.41	20.87

Table 5 displays the temperature and velocity contours of the simulation. As the velocity increase for each temperature, we can see that more yellow coloured area insides the drying chamber which indicates the temperature is higher compared to green coloured area [12]. As for velocity contour, most of the pattern at the outlet remain the same despite the increase in temperature. A high surface velocity is a crucial factor in the design of a successful dryer. The evaporated moisture from the surface would be carried out of the drier by suitable air speed. Furthermore, heated air conveyed the energy utilised to evaporate moisture at the coffee beans surface [13-15].

Table 5
Results of the simulation

Temperature (°C)	Velocity (m/s)		
	10	20	30
	Temperature Contour		
60			
90			
120			
	Velocity Contour		
60			
90			
120			

3.2 Future Recommendation

Despite the success of the experiments, it is possible that some modifications will be made to the results in the future. There are numerous possibilities for the future, including use a different type of distributor. The distributor that was used in this experiment is only one type and more distributor design is needed as the streamline flow will differ and will affect the heat distribution inside the drying chamber. Other than that, a different design of fluidized bed is also preferred as the current design does not fully efficient. From this simulation, it shows that when 60 °C of inlet temperature is used, only average 49 °C is recorded at the outlet of the fluidized bed which the heat loss is more than 18%.

4. Conclusions

Overall, the study achieves the study objectives. The study started with designing a fluidized bed dryer for coffee beans. Then the velocity streamline and heat distribution calculations were carried out using the Ansys Software, and more precisely by using the Fluid Flow (Fluent) system tool. The effect of difference between the velocity and the temperature have been determined based on the results obtained. The average temperature at the outlet of the fluidized bed will increase as the inlet velocity increase. Despite the fact that the difference in increase is not significant, the increase in intake velocity makes a difference. As for the average velocity at the outlet of the fluidized bed, the velocity remains consistent despite the increase of the inlet temperature.

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