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CFD Analysis of Empty Fruit Bunch Drying System in Biomass Processing Application

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Abstract

The global shift towards biomass energy reflects the growing recognition of its potential to provide clean and renewable energy while reducing carbon emissions and promoting environmental sustainability. Empty Fruit Bunch (EFB), a by-product of the palm oil industry, has emerged as a promising biomass fuel source; however, its high moisture content significantly reduces combustion efficiency, necessitating an effective drying process. This study examines the heat transfer and thermal characteristics within a drum dryer system used for EFB drying, aiming to determine the optimal inlet air temperature and velocity for efficient moisture removal. A three-dimensional model of the EFB drum dryer was designed using SolidWorks, and computational fluid dynamics (CFD) simulations were performed using ANSYS software. The inlet air temperature ranged from 120°C to 250°C, with a volume flow rate between 0.105 m^3/s and 0.185 m^3/s. Results indicate that increasing both inlet temperature and air velocity enhances the outlet air temperature, whereas the inlet flow rate mainly influences the outlet velocity. The highest outlet temperature achieved was 64.17°C, suggesting that the tested operating conditions were insufficient to achieve optimal drying efficiency. These findings provide valuable insights for scaling up the system under modified operating parameters or reducing the dryer length to minimize heat loss and improve drying performance.

1. Introduction

The global push towards renewable energy and sustainable industrial practices has intensified as nations strive to mitigate climate change and reduce greenhouse gas emissions [1]. Among various renewable resources, biomass, which is organic material derived from plants and animals, has emerged as a promising alternative for energy generation. It can be obtained from various agricultural sources such as sugar cane, rubber, and oil palm, particularly from oil palm Empty Fruit Bunches (EFB), which are abundant by-products of the palm oil milling process. In Malaysia, one of the world's largest palm oil producers, the accumulation of EFB poses both environmental and health challenges, including pollution and pest infestations [2]. Improper disposal methods, such as open burning or landfilling, further contribute to carbon emissions and air pollution. However, EFB also presents a valuable renewable energy opportunity. Utilizing EFB as biomass fuel not only mitigates waste disposal issues but also supports the country's energy diversification and sustainability goals. When used for electricity generation, biomass helps reduce greenhouse gas emissions by incorporating carbon dioxide release into the natural carbon cycle while preventing methane emissions that would otherwise result from the decomposition of organic materials. EFB can be directly converted into energy through pyrolysis, gasification, or combustion for heat and power generation or processed to produce biogas (methane) via anaerobic fermentation. Overall, transforming EFB and other agricultural residues into biomass energy offers a sustainable and environmentally friendly solution for cleaner energy production and effective waste management.

Emerging countries like Malaysia are experiencing a significant rise in global energy consumption driven by increasing GDP and population growth, which in turn places pressure on energy supply systems. Biomass, as a renewable energy source, offers environmental advantages by reducing greenhouse gas emissions while producing electricity, biofuels, and other bio-based products. Among various biomass resources, oil palm Empty Fruit Bunches (EFB) represent a major by-product with substantial energy potential. However, the direct combustion of untreated EFB can release air pollutants such as carbon monoxide, particulate matter, and volatile organic compounds, contributing to respiratory and environmental health concerns. To address this, the present study aims to enhance the efficiency of EFB as a sustainable replacement for fossil fuels, given that biomass energy is generally more cost-effective and environmentally friendly. Dried EFB exhibits superior combustion properties, resulting in lower emissions, higher energy conversion efficiency, and reduced handling and transportation costs due to its decreased weight and volume. Nonetheless, EFB contains high moisture content that must be reduced prior to combustion or thermochemical conversion, as excessive moisture lowers calorific value and combustion efficiency while increasing drying energy requirements. Therefore, drying serves as a crucial pre-processing stage in biomass-to-energy systems, directly influencing overall system performance and energy yield. This study employs SolidWorks software to analyze the fluid flow and thermal characteristics of the EFB drying system, aiming to improve heat transfer efficiency, achieve uniform temperature distribution, and ensure optimal airflow for effective moisture removal, ultimately contributing to a more efficient and sustainable biomass utilization process.

The rotary dryer is an industrial device designed to reduce or minimize the moisture content of materials through direct contact with heated gas. It is extensively used across various industries such as mineral processing, food production, and waste management to dry materials including coal, minerals, and biomass. In this process, materials are heated through convection, conduction, and radiation, while moisture evaporates inside the rotating drum. The rotary drum, equipped with an inner screw mixer, lifting flights, and copying boards, facilitates the movement and continuous mixing of materials to ensure efficient drying. This drying process is particularly important for biomass-based fuels used in power plants, as it significantly enhances combustion efficiency by lowering moisture content. Although several commercial designs of rotary dryers are already available in the biomass industry, many existing setups and operational configurations do not always meet the required moisture specifications. Structurally, the dryer consists of a rotating cylindrical drum that enables material to flow smoothly from the feed to the discharge end under gravity [3]. Internal flight fins lift the material and allow it to fall through a heated gas stream, either in co-current or counter-current flow [4]. The heat source can be supplied directly through combustion gases or indirectly via pre-heated air or other gases. Among various drying technologies, the rotary drum dryer is favored for its simple operation, robust design, and ability to handle large volumes of biomass efficiently. Furthermore, Computational Fluid Dynamics (CFD) has become an essential analytical tool for studying and optimizing rotary dryer performance, enabling researchers to simulate fluid flow, heat transfer, and temperature distribution under various operating conditions without extensive physical experimentation.

The optimal drying temperature for oil palm Empty Fruit Bunches (EFB) typically ranges between 142°C and 152°C when using steam as the drying medium. Research by Rosdanelli Hasibuan et al. (2004) indicates that moisture removal is maximized at approximately 142°C, with no significant improvement in drying rate beyond this temperature. Although superheated steam drying can reach temperatures up to 250°C, excessively high temperatures may alter the chemical structure of EFB, thereby reducing its heating value and performance as a solid fuel [5]. The efficiency of the drying process is also influenced by air flow velocity, which affects both heat and mass transfer. Studies show that an optimal air flow velocity for EFB drying ranges from 0.5 m/s to 2.5 m/s, while practical industrial applications often operate within the range of 0.105 m^3/s to 0.185 m^3/s to ensure effective moisture removal and temperature control (Ming, 2023) [6]. The rotary drum dryer operates by transferring heat to the material through a hot gas stream, achieving high thermal efficiency between 80% and 90%. Its drying rate can be controlled by adjusting parameters such as gas flow direction, temperature, and velocity. However, higher moisture content requires more energy and longer drying times, making the temperature of the drying medium a critical factor that must be carefully balanced to prevent overheating or material degradation [7].

The combustion and drying behaviour of biomass materials like EFB involve complex interactions between mass transport, convective and radiative heat transfer, chemical reactions, and multiphase fluid flow [8]. Recent studies have employed Computational Fluid Dynamics (CFD) simulations to better understand and optimize these processes. Previous researchers have also investigated the flow and thermal characteristics of an EFB drum drying system using 3D simulation software, finding that higher inlet air temperatures and flow velocities significantly improve outlet temperature and flow uniformity within the dryer [9-10]. By using CFD modelling to evaluate the gasification performance of several biomass feedstocks, including EFB, and demonstrated that flow dynamics and thermal properties have a strong influence on conversion efficiency. Despite these advances, there remains limited understanding of the optimal combination of inlet air temperature and flow rate for EFB drum drying systems. Existing studies have not comprehensively examined how varying inlet conditions between 120°C and 250°C, combined with volume flow rates from 0.105 m^3/s to 0.185 m^3/s, affect outlet air temperature, velocity distribution, and drying uniformity within the drum. Therefore, developing an optimized drying configuration is essential to enhance EFB's energy efficiency, drying performance, and overall practicality for large-scale industrial applications.

The geometry and design of the EFB drum dryer were developed using SolidWorks, while ANSYS Fluent was employed to conduct Computational Fluid Dynamics (CFD) simulations for analyzing the thermal and flow characteristics within the dryer. ANSYS Fluent provides a comprehensive platform for modeling fluid flow, heat transfer, and mass transfer in drying systems, allowing accurate simulation of complex interactions between hot air and biomass materials such as Empty Fruit Bunches [11]. Despite previous studies addressing the general performance of biomass dryers, limited research has been conducted on the detailed flow behavior and thermal distribution specific to EFB drying under varying inlet conditions. Therefore, this study aims to investigate the thermal and flow characteristics of hot air within an EFB drum dryer using CFD simulation. The drum dryer geometry was modeled in SolidWorks, and numerical analyses were performed in ANSYS to evaluate the effects of different inlet air temperatures and velocities on outlet temperature, airflow uniformity, and internal heat distribution. The findings from this research are expected to provide deeper insights into the drying behavior of EFB, enhance the overall energy efficiency of the process, and contribute valuable data for optimizing the design and scale-up of biomass drying systems in Malaysia's renewable energy sector.

2. Methodology

The methodology outlines the sequential process used to conduct the flow and thermal simulations and to achieve the objectives of this study. As illustrated in Fig. 1, the overall workflow begins with the design and modeling of the EFB drum dryer geometry using SolidWorks. The generated 3D model is then imported into ANSYS Fluent for pre-processing, which includes meshing of the computational domain and defining the appropriate boundary conditions. Following this, simulation setup parameters, such as inlet air temperature, velocity, and material properties, are assigned based on experimental and literature data. The CFD simulations are then executed to analyze the heat transfer, temperature distribution, and airflow characteristics inside the drum dryer. The obtained results are post-processed to evaluate temperature and velocity contours, outlet temperature profiles, and overall thermal performance.

2.1 Governing Equations

A mathematical model's governing equations explain how changes in one or more of the known variables affect the values of the unknown variables. The incompressible continuity equations for fluid flow are the governing equations for fluid flow, including the Navier-Stokes momentum equations and the energy equation.

Continuity equation:

$$\frac{\partial(u)}{\partial x} + \frac{\partial(v)}{\partial y} + \frac{\partial(w)}{\partial z} = 0 \quad (1)$$

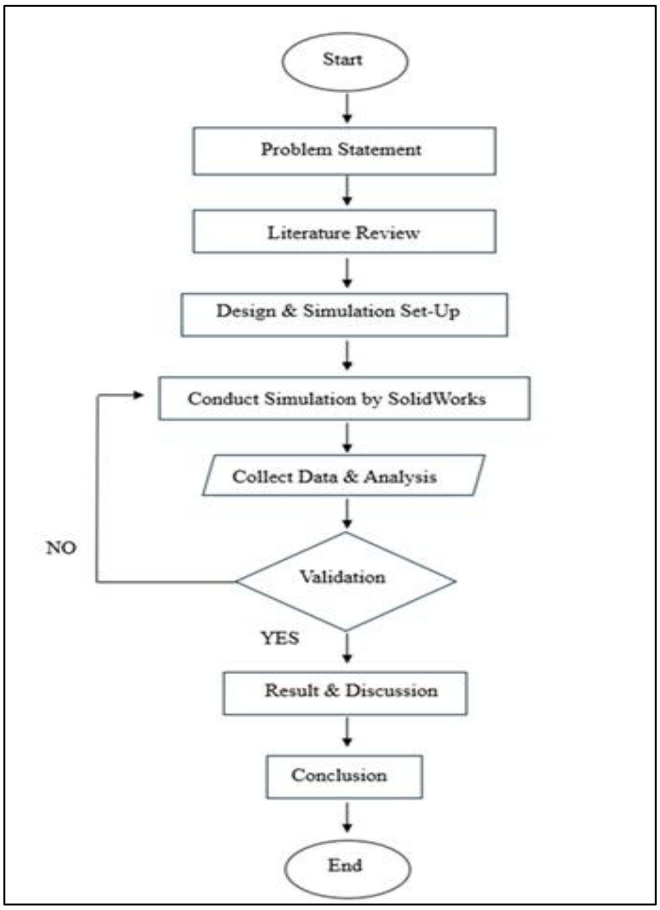


Fig. 1 *Methodology Flow Chart*

x-direction momentum:

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{\partial p}{p\partial x}+\gamma\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right] \quad (2)$$

y-direction momentum:

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{\partial p}{p\partial y}+\gamma\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right] \quad (3)$$

z-direction momentum:

$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{\partial p}{p\partial z}+\gamma\left[\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right] \quad (4)$$

Energy equation:

$$\rho C\left[\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right]=k\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right]+\dot{q} \quad (5)$$

2.2 Parameters and Boundary Conditions of The Model

Before performing the simulation, the parameter settings and boundary conditions were carefully defined to ensure accurate modelling of the thermal and flow behaviour within the drum dryer. The dryer model consists of two air inlets and one outlet, and the main body material is steel due to its high thermal conductivity and structural strength. The heated working fluid used in this simulation is air with the presence of water vapour to represent the drying environment of the EFB. The turbulence inside the drum dryer was confirmed through the Reynolds Number calculation, and therefore, the SST (k–ω) turbulence model was applied to capture the flow characteristics accurately. Additionally, the energy equation was activated in ANSYS Fluent to account for both convective and conductive heat transfer effects within the system.

The boundary conditions applied in the simulation are summarized in Table 1, which includes wall properties, initial temperature, and heat generation parameters. The walls were defined as stationary with a no-slip condition, and an initial temperature of 303.15 K was set for the entire domain.

Table 1 *Boundary conditions in CFD simulation*

Component	Initial Conditions
Wall	Stationary and no-slip wall
	Temperature: 303.15 K
	Heat generation rate: 0 W/m3
	Roughness constant: 0.5

The material properties used in the CFD model are listed in Table 2. Air and water vapour were considered as working fluids, while their physical properties, such as density, specific heat, and thermal conductivity, were defined according to standard reference values. The operating parameters used for the simulation are presented in Table 3. The inlet air temperature was varied from 130 °C to 250 °C, and the volume flow rate ranged from 0.105 m^3/s to 0.185 m^3/s. These combinations were selected to evaluate their influence on heat distribution and outlet temperature under different operating conditions.

Table 2 *Material settings for the simulation*

Material	Properties
Air	Density = 1 kg/m^3
	Specific heat, C_p = 1008 J/kg.K
	Thermal conductivity = 0.02953 W/m.K
	Roughness constant: 0.5
Water Vapor	Density = 0.597 kg/m^3.
	Specific heat, C_p = 1996 J/kg.K
	Thermal conductivity = 0.025 W/m·K

Table 3 *Parameter settings for inlet temperature and volume flow rate*

No	Temperature Inlet (Dryer Pipe) (°C)	Volume Flow Rate Inlet (Dryer Pipe) (m^3/s)
1	130	0.105
2	130	0.125
3	130	0.145
4	130	0.165
5	130	0.185
6	160	0.105
7	160	0.125
8	160	0.145
9	160	0.165
10	160	0.185
11	190	0.105
12	190	0.125
13	190	0.145

14	190	0.165
15	190	0.185
16	220	0.105
17	220	0.125
18	220	0.145
19	220	0.165
20	220	0.185
21	250	0.105
22	250	0.125
23	250	0.145
24	250	0.165
25	250	0.185

2.3 EFB Drum Dryer Design

The EFB drum dryer design and geometry were created by using SolidWorks and the dimensions according to the dimensions of diameter, height and wall thickness. The drum dryer has two pipe holes for hot air inlet and outlet with same diameter. The isometric view of EFB drum dryer is shown in Fig. 2 while side view of the EFB drum dryer was shown in Fig. 3.

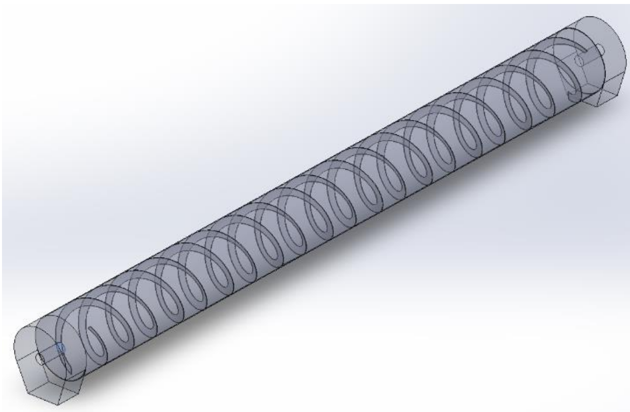


Fig. 2 *Isometric view of EFB drum dryer*

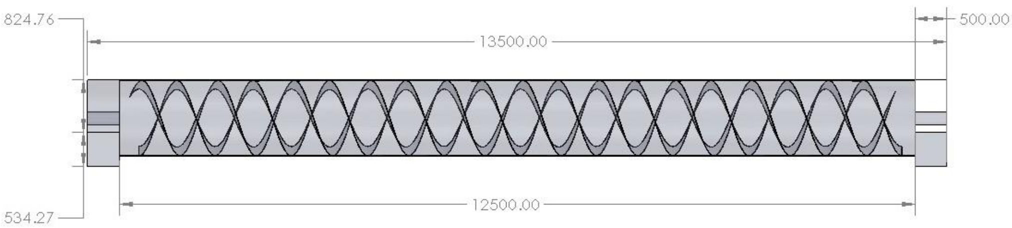


Fig. 3 *Side view of EFB drum dryer*

2.4 Procedure of Simulation Using Ansys

Before running the simulation using Ansys, there are several important working steps involved, as shown in Fig. 4. Firstly, the drum dryer geometry and design are created by using Ansys or other drawing tools. The simulation setup will then be adjusted to acquire the solution and results after the meshing has been applied to the fluid domain. After meshing, appropriate boundary conditions, material properties, and physical models are defined, including the turbulence model (*SST k–ω*) and the activation of the energy equation to account for heat transfer. Once the setup is complete, the simulation is executed to obtain the temperature and velocity fields, as well as the overall heat distribution within the drum. Finally, the results are post-processed to generate contour plots and graphical representations that visualize the flow behaviour and temperature gradients throughout the system.

Fig. 4 *Overview of simulation*

3. Results and Discussion

This chapter investigates the numerical analysis of heat flow and thermal characteristics of hot air inside a drum dryer, focusing on the temperature and velocity of the air at the outlet, as well as the heat distribution within the dryer. The study considers various temperature and velocity parameters.

3.1 Grid Independent Test

The grid independence test is used to determine the maximum element sizing for meshing that doesn't significantly change when the meshing size is changed. This test verifies the accuracy of numerical model results by comparing and ensuring no significant changes in results. In this study, four different meshing sizes (423741, 529204, 651234, and 864372) were used. The hot air velocity inside the drum dryer was compared using a graph of velocity versus distance from the inlet to the outlet, shown in Fig. 5. The grind independence test showed negligible differences in velocity results upon further grid refinement.

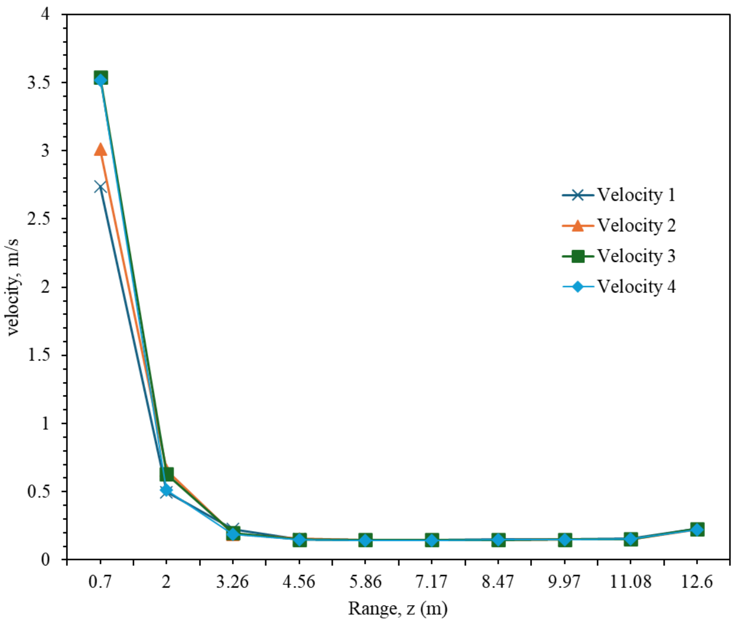


Fig. 5 *Velocity against distance inside drum dryer*

3.2 Validation Result

To validate the current simulation result, the simulation result of the temperature outlet is compared with the experimental result conducted by Haqif (2022). The parameters, inlet temperature and velocity, were provided by the experimental results. Fig. 6 depicts the deviation between the results.

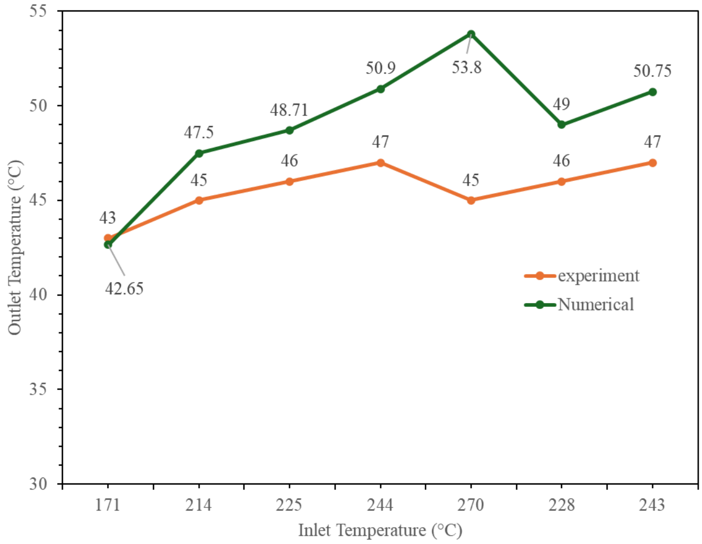


Fig. 6 *Outlet numerical and experimental temperature against inlet temperature*

Based on Fig. 6, the numerical result of the temperature outlet measurement has a little deviation from experimental results, with an average deviation of 7.5%. The result shows that the numerical result is higher than the experimental.

3.3 Temperature Analysis Inside Drum Dryer

Fig. 7 represents the result of the average temperature outlet against the volume flow rate. The result shows that increasing the inlet temperature leads to an increase in average temperature at the drum dryer outlet. At a constant temperature inlet and increasing volume flow rate, the outlet temperature also increases linearly. The best outlet temperature is achieved at the highest temperature and volume flow rate inlet, which is 250°C and 0.185 m/s. This indicates that outlet temperature can be increased by increasing the inlet temperature.

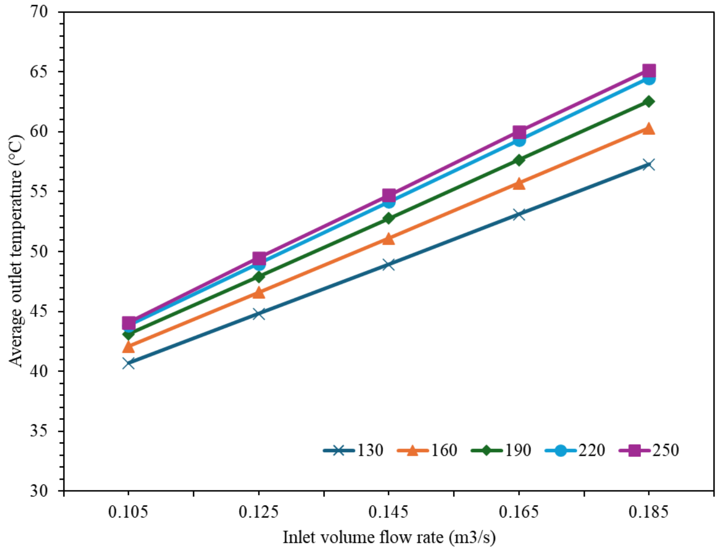


Fig. 7 *Average outlet temperature against inlet volume flow rate*

Fig. 8 displays the heat and temperature distribution inside a drum dryer with an inlet temperature of 250°C and a volume flow rate of 0.185 m^3/s. The temperature levels are displayed in 10 colour contours, with red indicating the hottest area and blue indicating the coolest. The cross-section plane temperature ranges from 250°C to 26.8°C. As the distance inside the dryer increases, the temperature decreases, with the area behind the lifting flight becoming hot near the inlet area but becoming cold as the distance increases. The design and dimensions of the lifting flight influence heat flow, blocking heat distribution from the inlet.

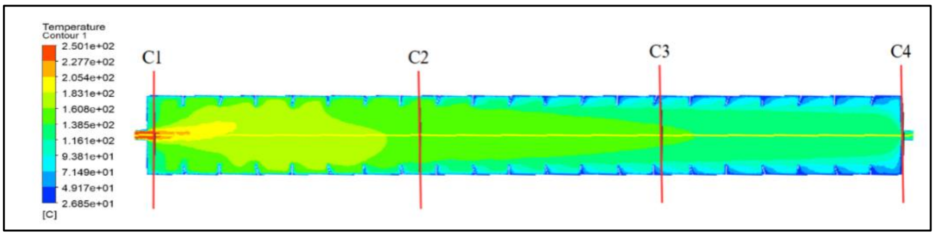
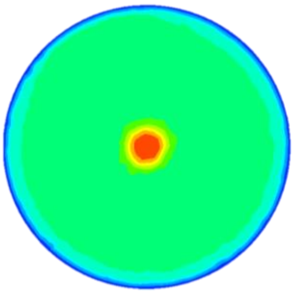
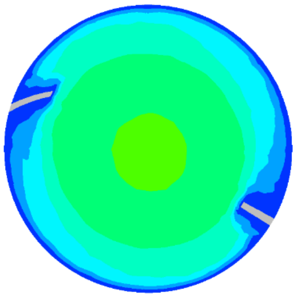
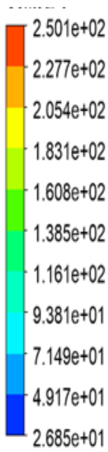
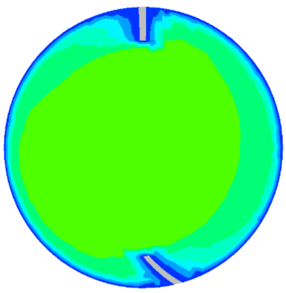
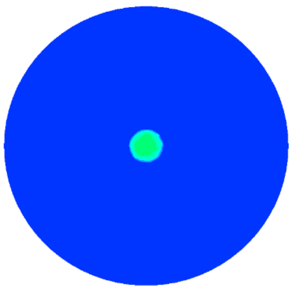


Fig. 8 *Temperature contour and isoline*

Table 3 shows the temperature distribution in a drum dryer is divided into four planes, which is plane 1 (C1), plane 2 (C2), plane 3 (C3), and plane 4 (C4). The middle area, which is the inlet area, provides the highest heat and temperature, with an average temperature of 126.14°C and a maximum of 250°C. The average temperature at plane 2 is 130.66°C and a maximum of 159°C. As the distance increases, the blue contour area increases, indicating heat loss. At plane 3, the green contour area and blue area are nearly the same, with a maximum temperature of 140.6°C and an average of 96.70°C. At plane 4, almost all areas are covered in blue, with only a small area at the middle having high temperatures. The maximum temperature at plane 4 is 130°C and the average is 65.15°C. The most optimal heat for drying EFB is found at planes 1 and 2, with temperatures between 130.65°C and 126.14°C. As distance increases, temperatures decrease to 96.70°C and 65.15°C, indicating insufficient heat for efficient EFB drying.

Table 3 *Cross-section at drum dryer for inlet temperature at 250 °C*

Plane	Results	Plane	Results	Temperature Range (°C)
C1		C3		
C2		C4		

3.4 Velocity Analysis Inside Drum Dryer

Fig. 9 represents the result of the output velocity of the drum dryer with the change in inlet temperature and volume flow rate parameters. Based on the results obtained, the value of velocity increases as the volume flow rate increases. However, when the temperature increases, the value of the velocity outlet for the same volume flow rate is constant and does not change. This indicates that the heat and temperature distribution do not influence the velocity behavior inside the drum dryer. The velocity can only be increased by increasing the volume flow rate. As observed, the velocity increases almost the same from 0.428 m/s to 0.512 m/s, 0.596 m/s, 0.673 m/s, and 0.756 m/s, despite the increase in the inlet temperature.

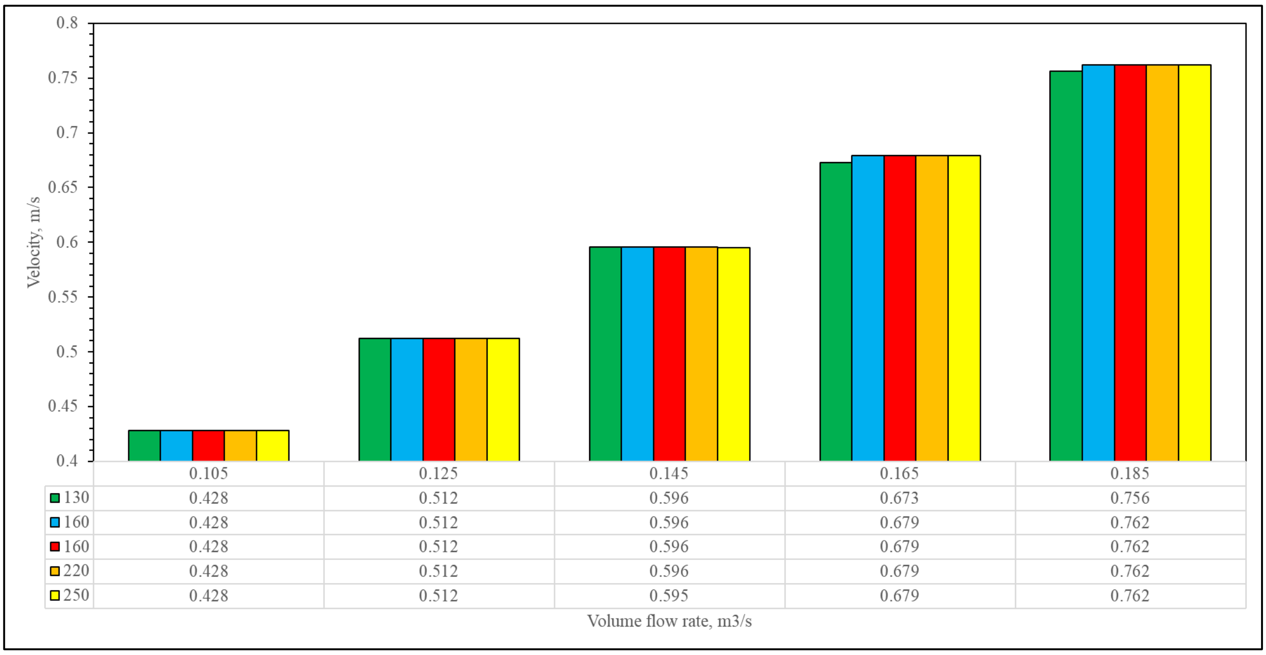


Fig. 9 *Velocity outlet that had a different volume flow rate*

Fig. 10 shows the contour of the velocity inside the drum dryer for the inlet temperature and volume flow rate of 250°C and 0.185 m^3/s. The temperature level is displayed in ten color contours, where red indicates the highest velocity and blue indicates the lowest velocity area. As observed, when the hot air enters through the inlet, the velocity is high but gradually decreases as the flow moves downstream due to the expansion of the drum geometry and internal flow resistance. However, near the outlet area, the velocity contour indicates a noticeable increase. This occurs because the inlet and outlet areas have smaller diameters compared to the main body of the drum dryer, resulting in higher localized flow velocity due to flow constriction. This observation agrees with the fluid dynamics principle that a reduction in cross-sectional area increases air velocity under constant mass flow conditions [12]. Furthermore, as the diameter of the drum increases, the overall velocity decreases, consistent with prior findings on flow behavior and energy loss along the axial direction of rotary dryers. Almost all the regions inside the drum are covered with blue contours, indicating that the velocity inside the drum dryer along most of the cross-section remains relatively constant, except at the inlet and outlet where turbulence and contraction effects are more pronounced

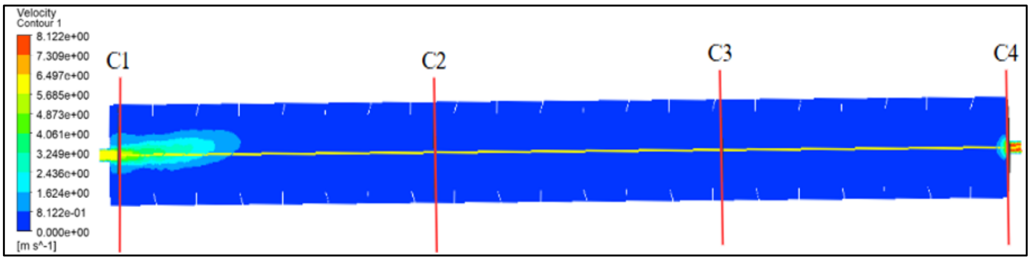
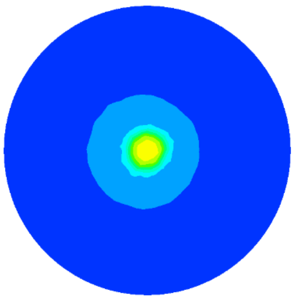
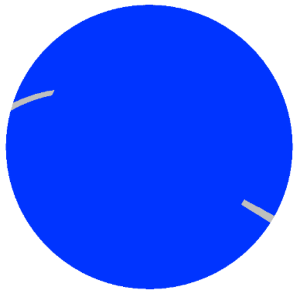
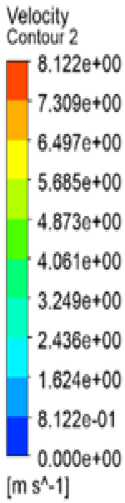
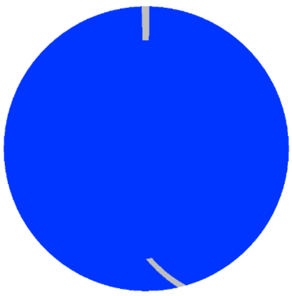
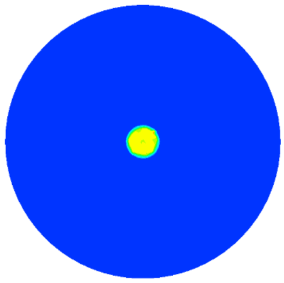


Fig. 10 *Velocity contour and isoline*

Table 4 shows the result of contour and isoline of the velocity for a cross section inside the drum dryer, which is separated into four planes: plane 1 (C1), plane 2 (C2), plane 3 (C3), and plane 4 (C4). At plane 1, the contour color at the middle is at the highest and begins to decrease as the diameter increases. This indicates that the velocity of hot air is only focused on the middle area inside the drum dryer [13]. Maximum velocity recorded at plane 1 area is 6.209 m/s, while the average velocity is 0.769 m/s. As observed, planes 2 and 3 are covered mostly with blue contours, showing that the velocity of hot air in this area is at its lowest. This is because, as the diameter and distance increase, the velocity begins to decrease [14]. The average velocity recorded at plane 2 and plane 3 is the same, which is 0.095 m/s. However, the maximum velocity recorded at plane 2 is higher, which is 0.197 m/s, compared to plane 3, which is 0.180 m/s. At plane 4, the most covered contour area is also blue, however, the velocity at the middle area shows increase. This is because the diameter at the outlet area is smaller compared to the drum dryer diameters. The velocity of the hot air depends on the volume flow rate, where an increase in volume flow rate will increase the velocity and otherwise. The volume flow rate can be increased by decreasing the area through the fluid flow.

Table 4 *Cross-section at drum dryer for inlet velocity at 0.185 m³/s*

Plane	Results	Plane	Results	Temperature Range (°C)
C1		C3		
C2		C4		

4. Conclusion

In conclusion, the thermal and flow characteristics simulation inside EFB drum dryer has been investigated. Based on the result obtained, the heat distribution and temperature inside the drum dryer were influenced by the value of temperature and volume flowrate inlet. However, the velocity inside the drum dryer was only influenced by inlet volume flowrate. The Ansys simulation was used to analyze the heat and flow characteristics inside the drum dryer. By using the SolidWorks software, the geometry and design of EFB drum dryer are created. Based on the data obtained, the highest temperature obtained in the drum dryer is at 65.17 °C by using the highest inlet temperature and volume flowrate parameters. The maximum temperature obtained at the at the 0.185 m^3/s for each inlet temperature inlet was 44.8°C, 49.87°C, 54.70°C, 60.00°C and 65.17°C. As for the velocity outlet, the data shows that as the inlet temperature increases, the velocity outlet for same volume flow rate are same. This indicates that the velocity does not influence the temperature inside the drum dryer. As the volume flow rate increases from 0.105m³/s to 0.125m³/s, 0.145m³/s, 0.165m³/s and 0.185m³/s the velocity outlet was increases from 0.428 m/s to 0.412 m/s, 0.596 m/s, 0.673 m/s and 0.756 m/s. The temperature obtained at the outlet was only 65.17 °C indicates that the insufficient of heat for EFB drying. This is because the optimal temperature required for EFB drying ranged from 120°C to 250°C. The high temperature can only be obtained near the inlet area inside drum dryer but decreases as the distance inside the drum increases.

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Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review. The contributions of all authors must be described in the following manner: The authors confirm contribution to the paper as follows: study conception and design: Wan Muzzaffar Amin Rosnawi, Ts. Dr. Shahrin Hisham Amirnordin; data collection Ts. Dr. Shahrin Hisham Amirnordin; analysis and interpretation of results: Wan Muzzaffar Amin Rosnawi, Ts. Dr. Shahrin Hisham Bin Amirnordin; draft manuscript preparation: Wan Muzzaffar Amin Rosnawi, Ts. Dr. Shahrin Hisham Amirnordin. All authors reviewed the results and approved the final version of the manuscript.

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