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Fluidized Bed Dryer with food processing Application Using Exploratory Data Analysis

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ABSTRACT

The Fluidized bed, a multi-phase innovation, makes a difference in useful contact in the midst of them, consequently, it is broadly utilized within the drying of vegetables, drug store businesses, chemical exchange, metallurgy, oil and in generating warm control. In fluidized bed forms, the strong and gas collaboration and responses in the midst of chemicals create sufficient factors which ought to be overseen, making the method exceptionally convoluted. Subsequently, to expect and assess diverse forms fluidized bed modeling and simulation are utilized all around. The prime intent of this think isn't as it were to conclude, but too to analyze and hone diverse parameters like Speed, discuss Temperature and Volume stream rate to accomplish the ideal drying rate in a fluidized bed dryer. A warming weapon with unstable temperatures is utilized to warm the air from the discuss blower, which encompasses an arrangement to switch between seven diverse speeds of discuss. The volume stream rate of the blower is consistent, i.e. 3.3 m3/min. The temperature of the discuss information (at both the entrance and exit of the drying chamber) is compared by employing a bland K-type thermocouple with 2 tests on an advanced show. What comes about, particularly the greatest drying rate is at that point approved to get the ideal values of the discuss speed, temperature, weight drop along the drying chamber and amount of dryable. The optimization of the specified parameters will be done utilizing one of the different optimization procedures accessible.

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1. INTRODUCTION

A bed without physical effects occurs when a large amount of solid sand material (usually contained in a holding tank) is placed under the right conditions and runs the risk of mixing the solid/liquid mixture that acts as a liquid. This can be done by spraying the particles with water under pressure. Create media that have the same characteristics and properties as ordinary liquids, such as the ability to flow smoothly under the force of gravity, using liquid-type methods [1]. The swelling name of this phenomenon is securitization. Most beds are used for many purposes such as catalytic fluid decomposition, heat, interface modification, application of coatings on solid materials, reactors, bed reactors, mass or heat, vegetable drying industry, etc.By analyzing and optimizing various parameters (air velocity, pressure drop depending on the height of the drying chamber, air temperature, drying capacity), the optimal drying speed can be achieved in fluid bed dryer[2].

The air temperature data, monitored at the inlet and outlet during the drying process, is captured by two probes equipped with thermocouples and digital displays. These results, crucially the maximum drying rate, undergo validation to ascertain the optimal values for air velocity, flow rate, and temperature [3]. Utilizing the Taguchi Optimization Technique within Design Expert'10 software, a meticulous optimization process is employed to fine-tune these parameters.

When air is permitted to flow upward through a solid layer, particles with greater momentum than the settling velocity are observed [4]. Some solid particles are entrained into the airstream, resembling the evaporation of liquid in boiling water, termed the liquid phase. Employing hot air within a reduced bed accelerates material drying, a feature integrated into an adjustable drying room for bed dryers, specifically designed for dry and desirable materials [5].

The controlled airflow traverses the room, heated to the desired temperature via a heater manipulated by the control panel, which regulates wind speed and temperature [17]. As the airflow intensifies, the water bed expands, inducing turbulent motions that aid in drying the material. The fluid bed dryer's high drying rate ensures rapid drying, allowing materials to remain free-flowing [6]. This integrated system underscores the efficiency of the drying process, where precise control and optimization of parameters contribute to accelerated and effective material drying.

It was found that three-dimensional moisture changes have a small effect on the diffusion coefficient as a function of size and that the drying rate has a significant effect on the diffusivity. For potatoes, beans, and peas, drying equilibrium is decreasing with the drying rate. Thermodynamic analysis is performed to change the entrainment and emission conditions of large particles in the bed drying process [7]. Effects of different conditions on fluid dynamics Thermal evaluations such as water rate, initial moisture content and inlet air temperature were performed for energy efficiency. The analysis using two materials, wheat and corn, showed that the drying capacity of fluid bed drying and the moisture removal rate was the lowest at the end of drying [8]. For corn, the thermodynamic energy is directly related to air temperature, but for corn. The diffusion coefficient depends on the temperature and moisture content of the particles, but the efficiency did not improve as the dry air temperature increased [18]. An experiment was conducted to observe the effect of water and determine the minimum evaporation rate by adjusting various parameters such as air temperature, wind, wind speed and the amount of dry matter, it must be higher than the dry matter determination rate. No flow effect was observed when the resolution rate was:

Drying in windy conditions is less likely to occur due to the impact of air currents. The water effect, wherein the minimum velocity required for effective drying is determined, is identified and documented. The process of food drying is typically categorized into three stages: pre-drying processing, dried material processing, and post-drying processing [9].

In the pre-drying process, the physical state of the material undergoing drying is crucial. The dried material can be subjected to atmospheric pressure or vacuum conditions. Volumetric heating or surface drying methods may be employed, and the material can undergo warming, seating, or movement. The storage stability of freeze-dried and vacuum-dried products is rigorously examined during this stage [10].

Throughout these processes, the quality of the final product is intricately affected. A comprehensive understanding of these stages is imperative for a profound comprehension of the intricate dynamics involved [19]. The interplay of these stages plays a pivotal role in determining the overall quality, texture, and shelf life of the dried food product, necessitating a thorough exploration and analysis of each step in the drying process.

2. LITERATURE REVIEW

[20] Presented a concrete instance demonstrating the application of an Exploratory Data Analysis (EDA) methodology to scrutinize and enhance a large-scale drug production procedure, specifically focusing on the drying phase of solid drugs (pharmaceutical granules) utilizing a fluid bed dryer. The challenge of optimizing energy consumption in fluid bed dryers for pharmaceutical granules has been effectively tackled, resulting in an average reduction of nearly 50% in the processing time of the fluid bed dryer per batch (averaging 1 hour per batch). Additionally, substantial energy savings were realized, amounting to 18.5 kWh per batch. This accomplishment was realized through the utilization of sophisticated analytical data exploration and pre-processing techniques.

[21] Explored the fluidized bed agglomeration of a plant protein powder blend by employing an açaí pulp binder to enhance its physical and handling characteristics. The blend was created by combining isolated pea protein powder and concentrated rice protein powder. A factorial design was employed to assess the impact of air temperature and binder flow rate on moisture content, particle size, and process yield during the investigation.

[22] Utilizing mechanical dewatering proved successful in reducing the moisture content of the powder to 45%. The introduction of vibration further improved the powder feed rate within the drying bed, even for powders characterized by moisture levels that typically exhibit minimal cohesiveness. Employing a dimensionless vibration number (ν) of 4, along with varying vibration amplitudes (A = 0.015 and 0.003 m),

led to distinct dynamic behaviors that impacted the solids feeding rate but had no effect on the mean Sauter diameter of the elutriated powder.

In [23], an analytical and simulation methodology is introduced to assess the thermal and hygroscopic properties of paddy at the outlet. The mathematical model presented in this study is designed to predict the optimal design of a dryer column. Through the utilization of a working model and simulation, the study examines the impacts of various design parameters such as initial paddy grain temperature, initial paddy moisture content, equilibrium moisture content, operational fluidization velocity of hot air, and more. The validation of the model for paddy grain is explored using a small-scale plug flow fluidized bed dryer.

3. DESIGN AND ANALYSIS

Anticipating a maximum discussed weight within the channel at 15 kN, the parameters for the Fluidized Bed Dryer (FBD) include a blower weight of 5 kg, a warm weapon weight of 1 kg, a safety factor of 5, and a drying chamber capacity of 5 kg. Utilizing these variables and the aspect ratio [11], the measurements of the channel were precisely calculated, employing the SolidWorks modeling program. The result is a comprehensive visual representation, displayed in the form of a detailed side view of the conduit in the FBD model [15].

This image serves as a valuable insight into the structural design and configuration of the fluidized bed dryer, offering a glimpse into how the components, weights, and safety factors are considered and integrated. Such detailed modeling is crucial for ensuring the structural integrity and operational efficiency of the fluidized bed dryer in the context of food processing applications. An isometric view of the modeled duct with dimensions is shown in Figure 1.

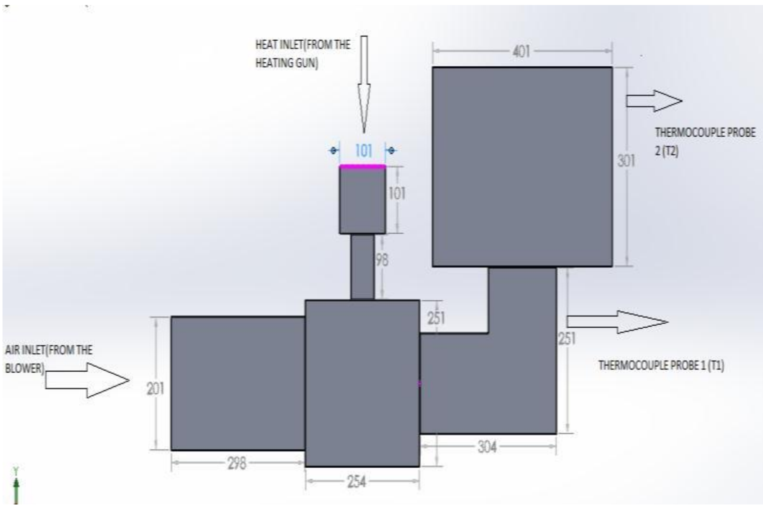

Figure 1. Isometric view of the modeled duct with dimensions

An isometric view of a modeled duct with dimensions provides a three-dimensional representation of the duct, incorporating length, width, and height dimensions. This view is crucial for visualizing the spatial arrangement of the duct components and understanding their relationships accurately. In the context of the fluidized bed dryer (FBD) mentioned earlier, an isometric view would showcase the duct's structural details, such as the length of the channel, the width of the duct, and the height of various components within it. This representation offers a holistic perspective, allowing observers to assess the overall form and proportions of the duct in a more intuitive manner.

The dimensions incorporated into the isometric view are essential for engineering considerations. They provide precise information about the scale and proportions of the duct, aiding in the assessment of its structural integrity, load-bearing capacity, and compatibility with other system components. Engineers and designers can use this visual representation to verify that the modeled duct aligns with safety standards, performance requirements, and the overall design objectives of the fluidized bed dryer system. Overall, the isometric view with dimensions serves as a valuable tool in the design, analysis, and optimization of complex engineering systems like the FBD.

Table 1. Tabulation of Results

No	Temperature	Pressure difference	Volume flow rate	Capacity	Weight loss(drying rate)
1	60	4	1.885	750	82.161
2	50	6	1.41	800	82.128
3	60	6	1.885	850	81
4	60	4	3.3	800	81.444
5	60	6	3.3	750	81.761
6	50	6	2.35	800	81.444
7	60	6	1.885	750	83.756
8	60	4	1.41	750	81.35
9	60	6	2.35	750	82.261
10	60	4	1.885	800	83.439

weight loss (drying rate) =+76.36 -0.64 * A[1] +0.21 * A[2] -1.86 * A[3] -1.31 * B[1] +1.16 * B[2] +2.75 * B[3]
+0.26 * C[1] -0.42 * C[2] +1.08 * C[3] -2.33 * D[1] +1.27 * D[2] +2.55 * D[3]

Significant heat loss was identified in the drying chamber, primarily attributed to inadequate circulation resulting from the absence of an exhaust system at one end [11]. The diagram provided illustrates the chimney structure atop the drying room, shedding light on the heat dissipation mechanism and its impact on thermal efficiency. The absence of a proper exhaust system contributes to the dissipation of valuable heat, adversely affecting the overall efficiency of the drying process.

Furthermore, shortcomings in the design become apparent, extending beyond heat management. Key functionalities, including the layout of the control panel for configuring the thermocouple and digital display thermometer, as well as the positioning of the pressure gauge and power box, lack intentional design [12]. These oversights not only hinder the user interface but also impede the optimization of the drying system's operational parameters. Addressing these design deficiencies is crucial for enhancing overall thermal efficiency, minimizing heat loss, and streamlining the functionality of the control panel for improved usability and precision in the drying process.

Upon completion of construction, ensuring the drying room's insulation is paramount to prevent heat loss and temperature variations, minimizing errors in the process [13]. To achieve robust insulation, a coating of Polyurethane (PU) foam is applied, acting as a solid protective layer. Following the application, any unevenness in the PU foam coating is meticulously addressed by using a grinder with a polishing tool, ensuring a smooth and uniform surface [20]. The composition process is essential to guarantee effective insulation, and the utilization of PU foam proves instrumental in achieving thermal stability.

For an additional layer of protection, the entire unit is sealed with aluminum cladding [14]. This cladding serves as a protective barrier, preventing heat loss and facilitating the maintenance of the required temperature within the drying room. The combination of PU foam insulation and aluminum cladding establishes a comprehensive defense against external influences, creating an environment conducive to precise and controlled drying processes. This meticulous approach to insulation contributes significantly to the efficiency and reliability of the drying system, ensuring consistent performance and minimizing potential disruptions due to temperature variations.

4. RESULT AND DISCUSSION

The application of Exploratory Data Analysis (EDA) in the context of a Fluidized Bed Dryer (FBD) with a focus on food processing reveals valuable insights into the system's performance and efficiency. The dataset collected during the experimental runs provides a wealth of information for analysis.

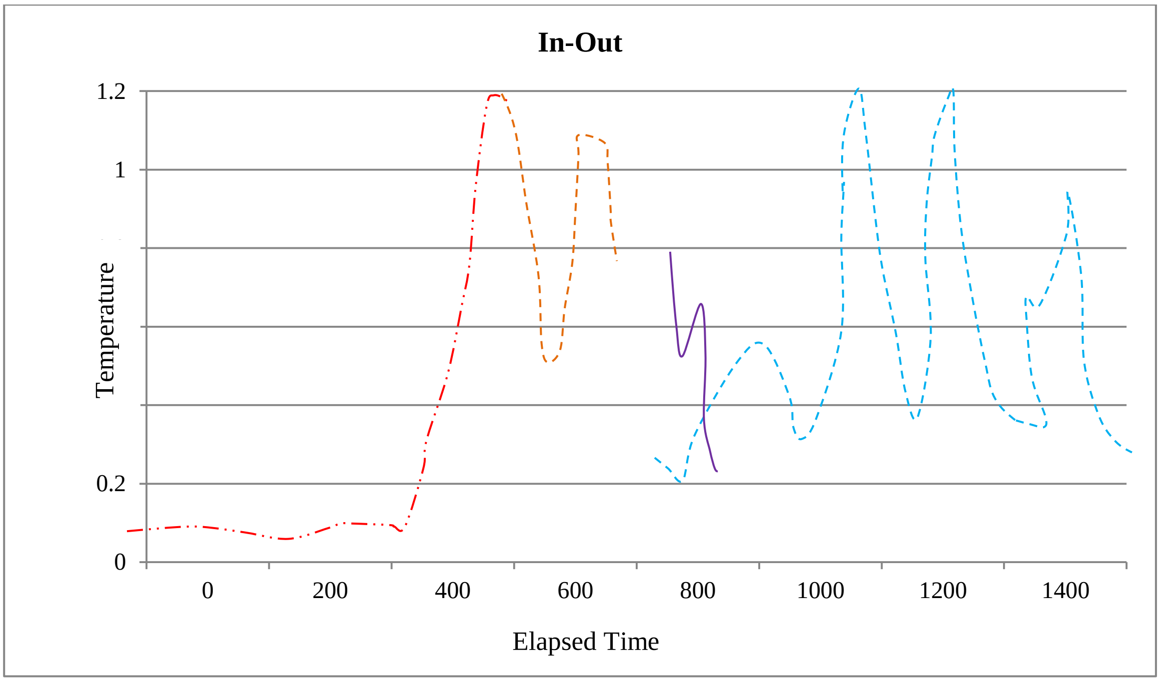

Figure 2. Drying Process Segment

In Figure 2, the x-axis represents the passage of time, indicating the elapsed duration, while the y-axis illustrates the temperature variance between the inlet and outlet air of the fluid bed dryer. This graphical representation allows for a visual examination of how the temperature difference evolves over the course of elapsed time, providing insights into the dynamics and behavior of the fluid bed dryer system. Exploratory Data Analysis (EDA) serves as a cornerstone in the study and optimization of Fluidized Bed Dryers (FBDs), particularly in the realm of food processing. This analytical methodology encompasses a multifaceted approach, providing nuanced insights that are integral to the enhancement of efficiency, the assurance of product quality, and the overall improvement of system performance in the context of FBDs.

1. Drying Efficiency:

Drying efficiency, a critical aspect of FBD operation, undergoes a meticulous examination through EDA. Parameters such as drying time and moisture content reduction are scrutinized, unveiling variations in drying rates across diverse food types. This granular understanding enables the development of targeted optimization strategies, tailoring drying conditions to specific products. The outcome is an improvement in overall efficiency, as well as a reduction in processing time—a vital factor in the optimization of food processing workflows.

2. Temperature and Airflow Patterns:

Temperature and airflow patterns within the fluidized bed represent another focal point of EDA. By employing this analytical approach, researchers gain a comprehensive understanding of the intricate interplay between temperature and airflow dynamics. This analysis proves crucial in identifying optimal operating conditions that not only enhance drying performance but also uphold the quality and safety standards of processed food. Through EDA, operators can fine-tune FBD parameters, ensuring that the thermal and airflow patterns align with the desired outcomes.

3. Energy Consumption:

Energy consumption during drying cycles becomes a focal point of investigation through the lens of EDA. This analytical tool allows for a nuanced assessment of power usage and efficiency. Armed with insights from EDA, strategies can be formulated to minimize energy consumption—a pivotal consideration in the contemporary landscape that places a premium on sustainable and cost-effective practices within food processing operations.

4. Product Quality:

The correlation between process parameters and the quality attributes of dried food products is a critical dimension explored through EDA. Beyond mere drying efficiency, EDA sheds light on how variations in parameters impact factors such as color, texture, and nutritional content. This knowledge becomes instrumental in implementing effective quality control measures, ensuring that the final products meet the desired standards of excellence.

5. System Stability and Robustness:

System stability and robustness are inherent challenges in the operation of fluidized bed dryers. EDA steps in to analyze the variability in system performance, providing valuable insights into the stability of the FBD. Understanding the factors contributing to fluctuations allows for the implementation of control strategies to ensure consistent and reliable operation. This proactive approach minimizes downtime and production disruptions, contributing to the overall reliability of the FBD system.

6. Anomaly Detection:

Anomaly detection, a crucial aspect of any operational system, is facilitated through EDA. By identifying unexpected trends or irregularities in the data, EDA acts as an early warning system for potential equipment malfunctions or deviations from desired process conditions. Timely detection through EDA enables corrective actions to be taken promptly, mitigating potential issues and ensuring the integrity of the drying process.

7. Process Optimization:

The overarching theme of EDA is process optimization. By uncovering patterns and relationships within the data, this analytical approach guides the optimization of drying processes. Empirical observations derived from EDA inform adjustments to parameters such as airflow rate, temperature, and product feed rate, leading to a holistic enhancement of overall system efficiency and performance.

In conclusion, the integration of Exploratory Data Analysis in the study of Fluidized Bed Dryers for food processing proves to be instrumental in the pursuit of operational excellence. The insights gained through EDA empower operators and researchers to make informed decisions, enhance efficiency, ensure product quality, and contribute to the advancement of food processing technologies. This holistic approach to data analysis strengthens the foundation for continued innovation and excellence in the field of food processing, aligning with the evolving needs of a dynamic and demanding industry.

5. CONCLUSION

The thermal bed, a versatile multi-phase technology, finds widespread use in industries such as vegetable drying, medicine, chemical production, metallurgy, petroleum, and thermal power generation due to its ability to foster strong adhesion between different components. However, the fluidized bed processes integral to this technology pose a challenge due to the complexity introduced by numerous variables stemming from gas-solid interactions and chemical reactions. To navigate this complexity, modeling and simulation techniques are employed for prediction and analysis. This study goes beyond mere determination by seeking to comprehensively analyze and identify critical parameters influencing the drying speed in bed drying. Key factors, such as air velocity, volumetric flow rate, and air temperature, are scrutinized for their intricate roles in the fluidized bed. Understanding the interplay of these variables is crucial for optimizing the drying process. By delving into the nuanced relationships within the fluidized bed, the research aims to provide insights that transcend quantitative observations, contributing to a qualitative understanding of the thermal bed's dynamics and enhancing its efficiency across diverse applications.

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