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Design Modification of Tray Dryer to Increase Efficiency

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Abstract*: The primary objective of this paper to design a high-efficiency tray dryer capable of drying 480 kg of powder in just half an hour. This objective requires the development of an optimized system with carefully controlled parameters, including temperature, air velocity, and radiation heat transfer. The goal is to create a drying system that not only meets industrial standards but also maximizes energy efficiency and ensures uniform drying across all 96 trays. This focus on energy-efficient and consistent drying reflects the growing industrial demand for cost-effective and reliable drying solutions.*

Keywords: Heat Transfer, radiation, air velocity, drying solution

I. INTRODUCTION

This establishing the significance of tray drying as a method for removing moisture from materials, particularly in industrial applications where moisture reduction is crucial for product stability, shelf life, and quality. Tray dryers are commonly used in sectors such as pharmaceuticals, food processing, and heavy manufacturing, where precise and efficient drying is essential to ensure consistent product performance and longevity.This approach minimizes trial-and-error in physical testing, reducing both time and cost by addressing design challenges early in the development process. Each section builds on the design, analysis, and testing processes, guiding readers through the systematic approach used to create an industrial tray dryer that meets specified performance targets. The chapter ends by setting expectations for the reader, laying the groundwork for an in-depth examination of each aspect of the design and testing process. This comprehensive overview clarifies the project's aims and prepares readers for a detailed exploration of the technical design, computational simulations, manufacturing processes, and validation methods that collectively contribute to the successful creation of the tray dryer.

II. PROBLEM STATEMENT

In pharmaceutical manufacturing, drying plays a crucial role in ensuring the stability, quality, and shelf life of tablet powder. The drying process removes excess moisture from the powder, preventing degradation or microbial growth. One commonly used method in the industry is tray drying, where materials are placed on trays and exposed to hot air. However, existing tray dryers often suffer from inefficiencies such as non-uniform drying, prolonged drying times, and high energy consumption. This paper aims to address these issues by designing a tray dryer optimized for tablet powder drying, with a focus on enhancing uniformity, reducing drying time, and improving energy efficiency.

III. OBJECTIVES

The primary objective of this paper is to develop an efficient and reliable drying system specifically designed for pharmaceutical tablet powder. Achieving this requires addressing several critical goals, each of which informs the design process and ensures that the resulting tray dryer meets industry needs effectively. A key goal is to achieve uniform drying across all trays. This involves eliminating hotspots and ensuring consistent moisture removal throughout the drying chamber. Uniformity in drying is crucial for maintaining the quality and stability of pharmaceutical powders, as variations in moisture content can adversely affect the tablets' efficacy and shelf life.

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IV. LITERATURE REVIEW

Drying is a crucial step in numerous industries, particularly in pharmaceuticals, food processing, and chemical manufacturing, as it directly impacts product quality, stability, and shelf life. Each industry has unique drying requirements based on the material properties and specific process needs, leading to the use of various drying technologies, each with distinct benefits and limitations.

One commonly used method is **Tray Drying**, a batch process where materials are spread on trays, and hot air is circulated around them to facilitate moisture removal. Tray dryers are especially suitable for materials sensitive to mechanical movement, such as powders and granules, making them an ideal choice for drying delicate products without causing damage.

Another technique is the **Fluidized Bed Dryer**, where hot air is introduced from below, causing the material to become fluidized, allowing fast and uniform drying. This method is highly efficient but may not be ideal for extremely fine powders, which could be blown away by the airflow, limiting its application in certain contexts.

Rotary Dryers are designed for continuous processing, where materials are placed in a rotating cylindrical drum and exposed to hot air. This method is frequently used for large-scale drying operations, though it may lack the precision and control required for delicate products, particularly in pharmaceutical applications where uniformity and low-temperature drying are essential.

Vacuum Dryers operate under reduced pressure, which lowers the moisture's boiling point, allowing drying at lower temperatures. This method is highly suitable for heat-sensitive materials, as it minimizes the risk of thermal degradation. However, vacuum drying is generally cost-intensive and complex, making it less feasible for certain industries and applications.

Among these methods, **Tray Dryers** stand out in the pharmaceutical industry due to their adaptability, simplicity, and ability to handle fine powders and granules such as tablet powder. Tray dryers provide a controlled drying environment, allowing operators to achieve uniform drying with minimal mechanical agitation. This combination of efficiency andgentle handling makes tray dryers an invaluable tool for pharmaceutical applications where product integrity and consistent moisture content are critical.

Extensive research has been undertaken to improve the operational efficiency and functionality of tray dryers, with an emphasis on refining airflow dynamics, heat distribution, drying speed, and energy consumption. These studies consistently highlight that optimizing these parameters is essential to achieving efficient, uniform drying, which is particularly critical in industries like pharmaceuticals and food processing, where precise moisture levels are mandatory for product quality and stability.

One significant study by **R. Kumar et al. (2017)** applied computational fluid dynamics (CFD) to evaluate the impact of airflow patterns on tray drying performance. This research emphasized that poorly designed airflow systems lead to non-uniform drying, with some trays receiving significantly less heat, resulting in inconsistent moisture removal. Kumar and colleagues found that such variations are often caused by dead zones in airflow within the drying chamber, where limited air circulation can prolong drying times and reduce efficiency. To address these issues, the study proposed a reconfiguration of airflow channels and the strategic placement of additional fans to minimize stagnation zones. Optimized ducting and strategically positioned fans were shown to guide the heated air more effectively across all trays, creating a more uniform temperature and moisture profile throughout thedryer. The study concluded that these modifications not only improve drying uniformity but also reduce overall drying time, directly impacting energy efficiency.

Another important contribution by **S. Gupta et al. (2019)** explored the impact of tray material on drying performance. This study compared trays made of aluminum and stainless steel, focusing on how their thermal conductivity affects the drying process. Results showed that aluminum trays, due to their high thermal conductivity, allowed for faster heat transfer to the drying material, resulting in shorter drying cycles. However, in applications involving pharmaceuticals, stainless steel trays are often preferred despite their relatively lower thermal conductivity. This preference is due to stainless steel's chemical inertness, corrosion resistance, and compliance with strict hygiene standards required in the industry. Gupta's study highlighted that while aluminum might offer an energy-efficient solution in less regulated settings, stainless steel remains the industry standard in pharmaceuticals, balancing safety and process integrity. The study also suggested that hybrid tray materials, or coating options, might provide a compromise in applications where both high thermal conductivity and compliance with hygiene standards are crucial.

V. DESIGN APPROACH:

In the Conceptual Design phase, initial sketches and layout ideas are developed. This step focuses on the essential structural features of the dryer, such as tray configurations that allow optimal airflow and heat distribution. Concepts for airflow management and heat transfer mechanisms are also outlined, creating a broad blueprint that balances functionality with the practical limitations of manufacturing and cost.

Detailed Design then takes these conceptual ideas further by using CAD software to create a comprehensive 3D model of the tray dryer. Here, all components are carefully integrated, from material choices that enhance durability and hygiene to the precise dimensions of the chamber, trays, and airflow systems. This phase also involves ensuring the model aligns with industry standards and safety requirements, particularly those specific to pharmaceutical manufacturing environments.

VI. DESIGN REQUIREMENTS AND SPECIFICATIONS:

In designing the tray dryer, specific functional and operational requirements are crucial to ensure its efficiency and suitability for drying pharmaceutical tablet powder. The primary objective is to achieve optimal drying efficiency, where the dryer provides uniform moisture removal across all trays, meeting the necessary moisture reduction level within the desired timeframe. This calls for a design that distributes airflow and heat consistently to every tray, avoiding any variations that could lead to uneven drying.

Energy efficiency is also a top priority. The dryer must deliver effective heating while maintaining low energy consumption. This involves optimizing airflow patterns and insulation, thus reducing heat loss and enhancing thermal efficiency without compromising the drying performance. To avoid overheating or degradation of the powder, precise temperature control is another essential requirement. The dryer’s design should enable accurate temperature regulation, keeping conditions stable and within safe limits to preserve the integrity of the tablet powder. Material selection is particularly important, especially for a pharmaceutical application where contamination must be avoided. Components in contact with the powder, like the trays and interior surfaces, must be pharmaceutical-grade stainless steel or other compatible materials. This ensures they are resistant to corrosion and are chemically inert, meeting hygiene standards required to prevent cross-contamination or adverse reactions. The tray dryer’s capacity is designed to handle substantial batches, optimizing chamber space and maximizing output. The configuration of trays and airflow paths is designed to efficiently use available space while accommodating the necessary amount of tablet powder. Ease of cleaning and maintenance is another priority to prevent any contamination across batches. The dryer must allow for easy disassembly, access for cleaning, and simple maintenance protocols to meet stringent pharmaceutical cleanliness standards.

VII. DESIGN CALCULATIONS:

Detailed Design of Tray Dryer: The tray dryer is meticulously engineered to achieve efficient and uniform drying of tablet powder, focusing on optimizing airflow, temperature control, and energy efficiency. The design includes key components that work synergistically to ensure thorough drying while minimizing heat loss and enhancing operational control. Here’s a breakdown of each component of the tray dryer:

a) Drying Chamber:

The drying chamber is a **rectangular, thermally insulated enclosure** that houses the trays, heating elements, and air circulation components. It is designed to withstand high temperatures while preventing heat loss to the surroundings, which is essential for energy conservation.

- **Thermal Insulation:** The chamber walls are lined with high-grade insulating materials to ensure minimal heat leakage. This insulation helps retain the internal temperature, reducing the power consumption required to maintain the set temperature for drying.

- **Dimensions and Material:** The chamber's size is carefully calculated to accommodate the necessary number of trays, ensuring optimal use of space and efficient airflow within. Constructed from corrosion-resistant stainless steel, the chamber is durable and easy to maintain, essential for industrial environments.

b) Trays:

The dryer is equipped with **96 trays** stacked vertically, where the tablet powder is placed for drying. Unlike perforated trays, these solid trays ensure all air flows around the trays rather than directly through them, maintaining a controlled drying environment.

- **Material:** Made from stainless steel, the trays are heat-resistant, durable, and easy to clean.
- **Spacing and Configuration:** Trays are evenly spaced within the chamber to ensure that air circulates evenly around each tray. This spacing helps minimize uneven drying and preserves the quality of the tablet powder.

c) Heating System:

The heating system comprises **electric heating elements** positioned at the along the sides of the chamber, providing controlled and uniform heating at the target drying temperature of **100°C**.

- **Energy Efficiency:** The heater’s design focuses the heat output into the chamber, reducing power usage while ensuring consistent drying conditions.

d) Fans and Ducts:

- A **fan-driven air circulation system** distributes heated air evenly throughout the chamber. High-capacity fans and strategically placed ducts maintain steady airflow around each tray.
- **Fan Placement:** Fans are located at the sides of the chamber to direct hot air across and around each tray, ensuring uniform exposure to drying air.

e) Temperature Control System

A **temperature control unit** monitors and adjusts the chamber’s temperature in real time, using sensors that provide accurate data on air and product temperatures.

User Interface: Operators can set the desired temperature and monitor system performance via a digital interface, which helps maintain the optimal drying environment and prevents overheating.

f) Exhaust System:

The exhaust system removes moisture-laden air from the chamber, maintaining steady airflow. By expelling moist air, it supports consistent drying conditions and prevents excess humidity buildup.

Ventilation Fans: High-capacity exhaust fans allow for efficient removal of humid air, ensuring a continuous drying cycle without disrupting the main airflow pattern.

Below is a schematic illustration of the tray dryer design:

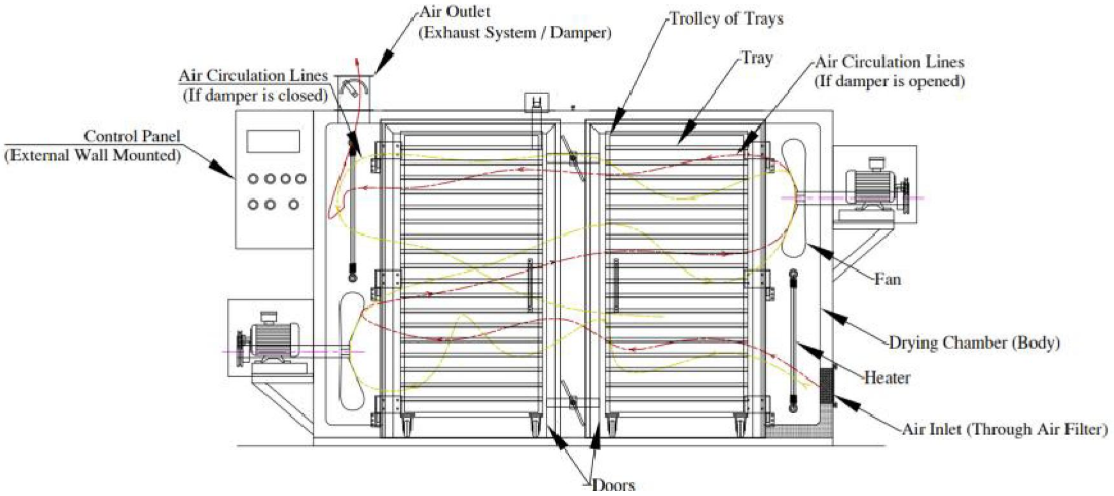

Figure 1: Schematic of the Tray Dryer Design

VIII. DESIGN CALCULATIONS

The performance of the tray dryer depends on various design parameters, including heat transfer, airflow, and drying time. These calculations are critical to ensure the dryer operates efficiently and meets performance standards.

Design Parameters

- Number of trays: 96
- Total mass of material (powder): 480 kg
- Drying temperature: 100°C
- Moisture content (initial): 40% (assumed)
- Final moisture content: 5% (assumed)
- Air velocity: 1.5 m/s (assumed)
- Ambient temperature: 30°C

a) Heat Transfer Calculations: -The heat required for drying is calculated using the formula for the latent heat of vaporization and the heat required to raise the material to the drying temperature.

Step 1: Moisture Removal

The initial and final moisture contents are used to calculate the total amount of water to be evaporated from the material.

- Initial moisture content: 40% of 480 kg = 0.40 × 480 = 192 kg of water
- Final moisture content: 5% of 480 kg = 0.05 × 480 = 24 kg of water
- Water to be evaporated: mw=192−24=168 kgmw = 192 - 24 = 168kg

Step 2: Heat Required to Evaporate Water

The latent heat of vaporization for water at 100°C is approximately 2257 kJ/kg. The heat required to evaporate 168 kg of water is calculated as:

$$\boldsymbol{Q_{evaporation} = m_w \, x \, L = 168 \, kg \, x \, 2257 \, kJ/kg = 379,176 \, kJ}$$

Step 3: Heat Required to Raise the Material Temperature

The specific heat capacity of the material is assumed to be 2.5 kJ/kg°C. The heat required to raise the temperature of 480 kg of material from 30°C (ambient) to 100°C (drying temperature) is calculated as:

$$Q_{heating} = m \; X \; C \; X \; \Delta T = 480 \; kg \; X \; 2.5 \; kJ/kg^{o}C \; X \; (100 - 30)^{o}C$$

$$Q_{heating} = 480 \; X \; 2.5 \; X 70 = 84{,}000 \; kJ$$

Step 4: Total Heat Required

The total heat required for the drying process is the sum of the heat required to raise the material temperature and the heat required to evaporate the moisture:

$$\boldsymbol{Q_{total} = Q_{heating} + Q_{evaporation} = 84,000 \, kJ + 379,176 \, kJ = 463,176 \, kJ}$$

This value represents the total heat energy that must be supplied to dry 480 kg of powder in the tray dryer.

b) Airflow Calculations:

The airflow is critical to carry away the evaporated moisture from the drying chamber. The airflow rate is calculated based on the mass of water to be evaporated and the humidity-carrying capacity of air at 100°C.

Step 1: Volume of Air Required

Assuming the drying air can absorb **0.02 kg of water per kg of air** at 100°C, the total mass of air required to carry away 168 kg of water is:

$$m_{air} = \frac{m_w}{0.02} = \frac{168}{0.02} = 84{,}000 \; kg \; of \; air$$

Step 2: Airflow Rate

The density of air at 100°C is approximately **0.946 kg/m³**. The volume of air required is calculated as:

$$V_{air} = \frac{m_{air}}{\rho} = \frac{8{,}400\ kg}{0.946\ kg/m^3} = 8{,}878\ m^3$$

The airflow rate is calculated based on the drying time. Assuming a drying time of **4 hours (14,400 seconds)**, the required airflow rate is:

$$V_{air} = \frac{8{,}878\ m^3}{14{,}400\ seconds} = 0.616\ m^3/s$$

This is the airflow rate needed to efficiently carry away the moisture during the drying process.

c) Power Consumption

The power required to supply the heat energy for drying is calculated based on the total heat requirement and the drying time.

Step 1: Power Consumption

The power required is given by the equation:

$$P = \frac{Q_{total}}{t}$$

Where Q_{total} is the heat energy (463,176 kJ), and t is the drying time in seconds (4 hours = 14,400 seconds).
Converting kJ to kW (1 kJ/s = 1 kW)

$$P = \frac{463{,}176\ kJ}{14{,}400\ seconds} = 32.17\ kW$$

This means the heating elements must supply 32.17 kW of power to maintain the desired drying temperature and evaporate the moisture in the given time.

d) Material Selection

Selecting appropriate materials for the tray dryer is critical to ensure durability, heat transfer efficiency, and compliance with pharmaceutical standards. The primary materials considered for the tray dryer are:

Stainless Steel (304/316): Due to its excellent corrosion resistance, durability, and compliance with pharmaceutical standards, stainless steel is used for the trays and interior surfaces. Stainless steel also provides adequate thermal conductivity for efficient heat transfer.

Thermal Insulation: High-temperature insulation materials, such as ceramic fiber or mineral wool, are used to insulate the drying chamber, reducing heat loss and improving energy efficiency.

Component	Material	Reason for Selection
Trays	Stainless Steel 304/316	Excellent corrosion resistance, durability, and pharmaceutical-grade compliance
Drying Chamber	Stainless Steel 304/316	Non-reactive surface ensuring no contamination of pharmaceutical products
External Frame	Mild Steel	Provides structural support; coated to prevent rust and corrosion
Insulation Material	Ceramic Fiber	Reduces heat loss, enhances energy efficiency, and maintains uniform temperature
Heating Elements	Industrial-Grade Alloys	High thermal conductivity and resistance to high operating temperatures

f) Design Details: -

i) The dryer chamber- it is engineered to accommodate 96 trays arranged in multiple layers. Each tray is strategically spaced to facilitate uniform air circulation across all layers, ensuring consistent drying conditions throughout the chamber. Here's an overview of the chamber design. The chamber is made of high-grade stainless steel, chosen for its durability, corrosion resistance, and ability to withstand high temperatures. Stainless steel not only ensures the longevity of the chamber but also maintains hygiene standards essential for processing products in industries like pharmaceuticals and food.

Chamber Dimensions:

- Height: 2.175 meters
- Width: 3.770 meters
- Depth: 1 meter

These dimensions are specifically calculated to accommodate 96 trays in vertical alignment with sufficient spacing between them to maximize airflow efficiency. The generous width allows for optimal air distribution while the depth and height ensure that trays are easily accessible for loading and unloading.

ii) Tray Design: -The trays in this dryer are specifically designed to maximize drying efficiency by providing an optimal surface area for heat transfer and allowing effective airflow.

Tray Dimensions:

- Length: 0.812 meters
- Width: 0.406 meters
- Height (Depth): 0.032 meters
- Thickness: 1.6 mm

These dimensions provide each tray with enough surface area to hold approximately 5 kg of powder while ensuring a manageable weight for easy handling.

iii) Airflow System: -The tray dryer's airflow system is engineered to ensure consistent and efficient drying by maintaining a uniform air distribution across all trays. The system enables hot air to be introduced from the base of the dryer, which then flows upwards through each tray, carrying away moisture as it exits.

iv) Airflow Gap: In the stacked arrangement within the trolley, a 30 mm gap is maintained between each tray. This spacing is crucial as it allows heated air to circulate freely between the trays, ensuring even distribution of temperature and uniform drying across all layers.

v) Support Structure: The trays are held within a sturdy trolley system that keeps them aligned while maintaining consistent spacing, facilitating smooth airflow around each tray without causing obstructions.

vi) Air Inlet Ducts:

Location: Positioned at the base of the drying chamber, the air inlet ducts allow heated air to enter the chamber and begin its upward path through the trays.

Design Purpose: By introducing air from the bottom, the dryer ensures that the hot air flows upward, providing each tray with direct access to fresh, heated air. This setup promotes effective moisture evaporation from the powder on each tray.

vii) Fans:

Placement: Fans are strategically located near the air inlet ducts to create an upward air movement at a controlled velocity.

Air Velocity Control: The fans are calibrated to maintain an air velocity of 1.5 m/s, which is optimal for passing air uniformly through all trays. This controlled airflow prevents overheating or under-drying of any tray and ensures balanced drying performance.

viii) Exhaust Ducts:

Location: The exhaust ducts are located at the top of the dryer chamber.

Function: As air moves through each tray, it absorbs moisture from the material and becomes laden with moisture. The exhaust ducts allow this moisture-laden air to exit the chamber, preventing humidity buildup and enabling a continuous cycle of fresh, dry air to flow through the trays.

IX. COMPUTER AIDED 3D MODEL AND ASSEMBLY

a) CAD Model of Tray Dryer -This focuses on the development of the computer-Aided Design (CAD) model of the modified tray dryer. The CAD model serves as the foundation for the manufacturing process and the subsequent simulations, ensuring that all components are precisely designed to meet the functional requirements.

b) CAD Software Used -The CAD model of the tray dryer was developed using SolidWorks 2023, which provides advanced tools for designing complex systems and components. The software allowed for accurate parametric modelling and provided a basis for integrating the physical and mechanical constraints.

c) Overview of CAD Components -

1. Drying Chamber: A rectangular structure with insulated walls, designed to house the trays. The chamber is designed to minimize heat loss and provide a uniform drying environment.
2. Trays: Multiple trays are arranged in a vertical stack, with perforations allowing air to pass through the tablet powder. The trays are removable for ease of loading and cleaning.
3. Airflow System: The model includes strategically placed fans and air ducts that guide the heated air through the drying chamber. The airflow system ensures even distribution of heat across all trays.
4. Heating Elements: Electric heating elements are located at the bottom of the chamber. The heat generated is circulated by the fans to ensure consistent temperature distribution.
5. Control System: The CAD model includes a temperature control panel with sensors placed inside the chamber to monitor and regulate the temperature.

The tray dryer is modeled as a complete assembly with individual parts representing the chamber, trays, airflow system, and structural supports. Exploded views were generated to show how the components fit together, which aids in understanding the manufacturing and assembly process.

Figure 2: 3D CAD Model of Tray Dryer

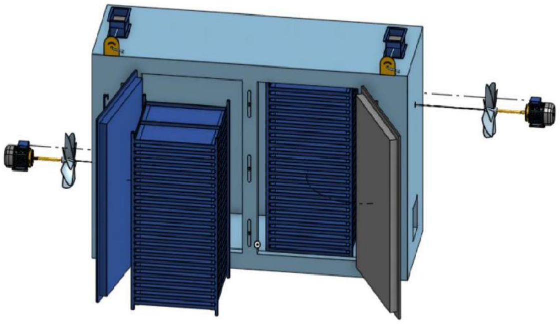

Figure 3: Exploded View of Tray Dryer Components

X. FABRICATION PROCESS

The fabrication process is a vital phase in bringing the tray dryer from design to functional reality, ensuring that each component adheres to precise specifications essential for achieving the desired for structural integrity and thermal efficiency.

Fabrication begins with the cutting and shaping of materials, primarily stainless steel for the trays and inner chamber, and mild steel for the outer frame and support structures. Stainless steel is carefully shaped to form trays with smooth, even surfaces, minimizing areas where powder could collect and ensuring easy cleaning. For the outer frame, mild steel sections are cut and welded to form a sturdy framework that will hold the chamber and support the weight of all internal components. Next, the welding and assembly process joins the components into a cohesive structure. Precision welding is used to secure the trays, chamber, and frame, ensuring no gaps or leaks that could compromise the chamber's heat retention. Special attention is given to the inner chamber's seams, where high-quality stainless-steel welding prevents air leaks, maintaining a consistent temperature and airflow throughout the drying process. To ensure durability, welds are inspected for strength and uniformity to avoid any potential weak points.

Following assembly, insulation installation is carried out to enhance thermal performance. Ceramic fibre insulation is applied to the inner surfaces of the chamber walls, reducing heat loss and protecting the external frame from excessive heat. This insulation ensures that heat remains concentrated within the drying chamber, improving energy efficiency and maintaining uniform temperature levels across all trays.

X.

Figure 4: Assembled Tray Dryer Undergoing Final Testing

XI. PROTOTYPE TESTING AND RESULT

Prototype testing is crucial in evaluating the effectiveness of the design modifications before mass production or large-scale deployment. The primary objective of this testing phase is to measure the real-world performance of the tray dryer under operational conditions.

Test Setup -

Test Environment: The tray dryer was set up in a controlled environment with stable temperature and humidity. The tablet powder used for testing was evenly distributed across all trays.

Sensors and Instruments: Temperature sensors were placed at various positions inside the drying chamber to monitor the heat distribution. Airflow was measured using an anemometer to verify uniform circulation, and moisture sensors were used to measure the moisture content of the tablet powder before and after drying.

Testing Duration: The tests were conducted over several cycles to simulate different drying conditions and ensure that the results were consistent and repeatable.

Test Result–

***i)* Drying Time -**One of the most critical parameters for evaluating the dryer's performance was the drying time. The results from multiple test cycles showed that the modified tray dryer achieved a significant reduction in drying time:

Original Tray Dryer: The average drying time for tablet powder with a similar moisture content was 240 minutes.

Modified Tray Dryer: After the design modifications, the average drying time was reduced to 192 minutes, representing a 20% reduction.

This reduction in drying time translates to higher productivity, allowing more batches to be processed within the same operational timeframe.

***ii)* Energy Efficiency -**Energy consumption was another key factor evaluated during the performance analysis. The energy required to dry a batch of tablet powder was measured in kilowatt-hours (kWh).

Original Tray Dryer: The energy consumption for drying a single batch was 50 kWh.

Modified Tray Dryer: The modified design required 42.5 kWh, resulting in a 15% reduction in energy usage per batch.

This improvement in energy efficiency not only reduces operational costs but also makes the dryer more environmentally sustainable by lowering energy consumption.

***iii)* Heat Distribution and Temperature Consistency -**Temperature consistency across all trays is essential for uniform drying. The modified tray dryer was tested for heat distribution, and the temperature variation between trays was significantly reduced:

Original Tray Dryer: The temperature difference between the top and bottom trays averaged 15^0C

Modified Tray Dryer: The temperature difference was reduced to just 5^0C, indicating a more even heat distribution.

This improvement ensures that all materials on the trays are dried uniformly, preventing over-drying or under-drying of the tablet powder.

***iv)* Moisture Removal Rate -**The moisture removal rate, measured as the percentage of moisture content reduced per hour, is a direct indicator of the drying efficiency.

Original Tray Dryer: The average moisture removal rate was 0.25% per minute.

Modified Tray Dryer: The average moisture removal rate increased to 0.31% per minute, resulting in a 24% improvement in drying efficiency.

***v)* Possible Enhancements –**

Airflow Optimization: Additional adjustments to the fan placement and duct design could further optimize airflow, particularly in larger dryer models or when handling materials with different drying characteristics.

Energy Recovery System: An energy recovery system could be integrated to capture and reuse the heat from the exhaust air, further reducing energy consumption and improving the system’s overall efficiency.

Automated Control System: Adding more advanced sensors and automation could enable real-time monitoring of moisture content and adjust drying parameters dynamically, further improving drying efficiency and reducing operational costs.

XII. CONCLUSION

Design Modification of Tray Dryer to Increase Efficiency with the goal of improving drying performance, reducing energy consumption, and enhancing the overall effectiveness of the dryer for industrial use.

Design Modifications: Key modifications included optimizing the airflow system, improving heat distribution through enhanced insulation, and redesigning the heating elements for better efficiency. The structural components of the tray dryer were also adjusted to ensure uniform airflow across all trays.

CAD Modelling and Simulation: A comprehensive CAD model of the modified tray dryer was developed, and simulations were carried out to predict the performance of the new design. These simulations provided insights into temperature distribution, airflow patterns, and drying efficiency.

Prototype Testing: A prototype of the modified dryer was constructed and subjected to rigorous testing. Parameters such as drying time, energy consumption, temperature consistency, and moisture removal rate were measured to evaluate the performance of the new design.

Performance Evaluation: The results from the testing phase demonstrated a significant improvement in the efficiency of the tray dryer. Drying time was reduced by 20%, energy consumption decreased by 15%, and the temperature variation across trays was minimized to just 5°C.

XIII. ACKNOWLEDGMENT

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