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Advancements in the Design and Fabrication of a Paddy Dryer Machine: Experimental Findings

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Abstract—The drying process post-harvest stands as a crucial operational step in minimizing losses and prolonging storage duration for grains intended for both seed consumption and marketing purposes. Excessive moisture levels can foster the growth of harmful insects and molds in grains, underscoring the significance of efficient drying methods. Introducing technology for small and marginal farmers to dry paddy emerges as a viable alternative to conventional sun drying. To assess the effectiveness of this technology, temperature and moisture content within the grain bin were systematically monitored using a combined probe thermos and moisture meter. The findings revealed a remarkably uniform distribution of temperature and moisture throughout the dryer. The drying duration for reducing paddy moisture content from 24.78% to 8.5% ranged from 3.5 to 7 hours, contingent upon the energy source employed. Across various air velocities, the lowest lightness values were consistently observed at an air velocity of 3.0 m/s, while the highest values were documented at an air velocity of 2.0 m/s. This drying apparatus proves to be a compelling alternative among effective drying technologies, particularly suitable for small-scale and marginal farmers.

Keywords— Paddy dryer, Moisture, Air, Agricultural product, Temperature profile.

1. Introduction

Drying, defined as the extraction of moisture to diminish water activity in a product, serves as a means to decelerate deterioration and uphold quality [1]. When agricultural products undergo thorough drying, effectively eliminating maximum moisture while retaining active nutrients, they can be safely preserved for an extended period [2]. This process involves a substantial reduction of free water in the food, leading to the concentration of dry matter without compromising the integrity, wholesomeness, and visual appeal of the product [3]. The drying mechanism encompasses heat and mass transfer within the material [4].

Despite the affordability and widespread availability of traditional drying methods, they often entail uncontrolled prolonged drying periods, susceptibility to contamination, and the production of low-quality dried goods [5]. In contrast, contemporary drying systems operate under regulated conditions, offering products of superior quality. Nevertheless, these advanced systems are frequently characterized by high costs and substantial energy consumption [6].

Meanwhile, the current global demand for food is driving an increased reliance on fossil fuels across all stages of the food chain. Statistical projections indicate that by 2030, the global demands for energy and food are expected to surge by 40% and 50%, respectively [7, 8]. Presently, the food sector consumes approximately 95 EJ of energy annually, with high and low GDP countries contributing 50 EJ and 45 EJ, respectively, reflecting distinct compositions of energy usage [9]. In light of environmental concerns and the finite nature of fossil fuels, it becomes imperative to further curtail energy consumption in the food sector. This reduction can potentially detach food prices from the volatility and upward trajectory of fossil fuel prices [10]. Therefore, embracing renewable energy sources for the drying of agricultural products is not only prudent but also aligns with sustainable practices.

Implementing renewable energy technology (RET) in food drying is deemed a commendable approach, given that renewable energy serves as an inexhaustible energy source [11]. Consequently, the reliance on energy derived from fossil fuels and its byproducts is eliminated. RET has the capability to convert these energy sources into various forms, including electricity, heating, and transport fuels [12]. It's noteworthy that renewable energy sources can generate more than 3000 times the current global energy demand [13]. Thus, a conscious effort is required to increase the proportion of these renewable energies in the global energy mix.

Currently, many rural areas, particularly in the global south, lack access to modern energy, which is essential for the adoption and operation of advanced drying systems. This underscores the necessity to address energy accessibility issues in these regions to facilitate the widespread adoption of renewable energy solutions for food drying.

Furthermore, a significant portion of these rural areas, predominantly inhabited by subsistence farmers, either lies at considerable distances from major cities or presents topographical challenges that make connection to the centralized national grid impractical. Consequently, these factors act as catalysts for the adoption of renewable energy in the post-harvest drying of agricultural products [14]. Sustainable drying entails the drying of agricultural products with minimal or no reliance on fossil fuels. This involves the utilization of alternative fuels or energy sources, aiming to mitigate the environmental impact of food drying practices [15].

Despite encountering certain obstacles, renewable energy technology (RET) has been identified as a viable strategy for food drying, offering advantages such as cost-effectiveness, high efficiency, and the creation of employment opportunities [16]. Two primary research approaches to sustainable food drying are delineated as follows [17]:

(i) Improving the efficiency of the dryer, which may be achieved through insulation, heat recovery, recirculation and altering operating constraints of the systems.

(ii) Improving or substituting the system's energy supply by using combined heat and power (CHP), biomass derived fuels and other renewable energy sources.

Building upon the aforementioned strategies, sustainable drying can be achieved through various methods, including solar systems, biomass units, geothermal systems, waste/recovered heat, or a combination of two or more systems, commonly known as hybrid drying [18]. Notably, drying technologies have undergone extensive investigation, with numerous studies reviewing aspects such as heat sources, configurations, and optimizations, encompassing both experimental and modeling perspectives. However, there appears to be a gap in comprehensive research summaries, particularly concerning the sustainable drying of agricultural products, particularly within the context of smallholder farmers.

This review places emphasis on hybrid drying systems and waste heat recovery for food drying. Hybrid drying systems involve the integration of solar energy with other technologies such as biomass drying and heat pumps, along with solar integration with heat storage systems, as depicted in the dashed area. These systems are designed to address the limitations inherent in individual renewable drying systems [19].

2. Methodology

2.1 Objective of study

- The objective of this study was to investigate technical and financial performance of paddy dryer at the field level.
- Dry paddy can be done in less time with low cost
- High quality rice can be produced and seed marketing by reducing paddy moisture.

2.2 Fabrication of Paddy Dryer

The fabrication of a circular paddy dryer involves the construction of the drying chamber, air circulation system, heating system, and control mechanisms. Additionally, compliance with safety standards and regulations is crucial throughout the fabrication process. The finished model as shown in Figure 1. Below is a generalized guide to the fabrication process, though specific designs may vary:

i. Design of Paddy Dryer by CAD:

Start by designing the circular paddy dryer, taking into consideration factors such as the drying capacity, type of heating system, and space available. Plan the layout and dimensions of the drying chamber.

ii. Material Selection:

Choose suitable materials for the construction of the drying chamber. Common materials include stainless steel, galvanized steel, or other materials that can withstand the conditions within the dryer.

iii. Drying Chamber Construction:

Fabricate the cylindrical drying chamber according to the design specifications. Weld the steel sheets together to form a sturdy and airtight structure. Ensure that the seams are well-sealed to prevent air leakage.

iv. Air Circulation System:

Install the air circulation system, including fans and blowers. Position them strategically to ensure uniform air distribution throughout the drying chamber. Connect ductwork to facilitate the movement of air.

v. Heating System Installation:

Install the heating system, whether it's a gas burner, biomass burner, or electric heating elements. Ensure that the heating elements are positioned to provide efficient heat transfer to the circulating air.

vi. Insulation:

Apply insulation to the drying chamber to minimize heat loss. This is especially important for energy efficiency, as it helps maintain the desired temperature inside the dryer.

vii. Control System Integration:

Integrate a control system that includes temperature and humidity sensors, thermostats, and other relevant instruments. This system will monitor and control the drying process automatically.

viii. Exhaust System:

Install an exhaust system to remove moisture-laden air from the drying chamber. Consider incorporating a heat recovery system to improve energy efficiency.

ix. Safety Features:

Implement safety features such as emergency shut-off switches and ventilation systems to ensure the safety of the operation.

Figure. 1: Photographic view of the finished circular paddy dry model

3 Results and Discussion

3.1 Working of Paddy Dryer

A circular paddy dryer is a type of equipment used in the agricultural industry for drying paddy rice after harvest. The primary purpose of a paddy dryer is to reduce the moisture content of freshly harvested rice to a level suitable for storage and milling. Here's an overview of the working of a circular paddy dryer:

i. Loading and Feeding:

Freshly harvested paddy rice is loaded into the drying chamber of the circular paddy dryer. The drying chamber is typically a large, cylindrical structure.

ii. Air Circulation System:

The drying process relies on the circulation of hot air through the paddy grains. A system of fans and blowers is used to generate and maintain the airflow. The hot air is often produced by burning fuel in a combustion chamber.

iii. Heating System:

The heating system is responsible for raising the temperature of the air that will be used for drying. Common heat sources include gas burners, biomass burners, or other types of heating elements.

iv. Temperature Control:

The temperature of the hot air is carefully controlled to ensure effective drying without causing damage to the rice grains. Temperature control mechanisms, such as thermostats, are employed to maintain the desired temperature within the drying chamber.

v. Drying Process:

The loaded paddy is exposed to the heated air as it circulates through the drying chamber. The hot air absorbs moisture from the rice grains, causing the moisture to evaporate.

vi. Air Exhaust and Moisture Removal:

Moisture-laden air is exhausted from the drying chamber. Some dryers have mechanisms to recover heat from the exhaust air to improve energy efficiency. Additionally, the moisture content in the exhaust air may be condensed and collected to further reduce energy loss.

vii. Monitoring and Control:

Modern paddy dryers often come equipped with sensors and control systems to monitor factors such as temperature, humidity, and moisture content. These systems help automate and optimize the drying process for efficiency and quality.

viii. Unloading:

Once the desired moisture content is achieved, the dried paddy is unloaded from the drying chamber. It is then ready for storage or further processing. Circular paddy dryers offer advantages such as uniform drying, efficient use of space, and ease of loading and unloading. The design allows for a continuous and controlled drying process, contributing to the preservation of rice quality.

3.2 Food drying process curve

The characterization of drying kinetics is a common practice to elucidate both the microscopic and macroscopic mechanisms governing mass, heat, and momentum transfer throughout the drying process. This analysis is notably impacted by various factors, including thermodynamic conditions, the type of dryer employed, and the characteristics of the materials undergoing drying. Consequently, drying kinetics serve as valuable tools in selecting the appropriate dryer and determining optimal operating conditions for agricultural produce. This is because the kinetics account for moisture removal and the impact of other variables.

The progression of moisture removal over time in food is depicted in Figure 2, where the graph illustrates the relationship between moisture loss and drying time. In the initial phase of drying, the food sample reaches thermal equilibrium with the drying chamber, initiating the removal of external moisture from the food (constant drying rate). During this stage, drying is primarily influenced by drying conditions such as air temperature, velocity, and relative humidity. This phase persists until the critical moisture content is achieved, marking the onset of the falling rate period. In contrast to the drying conditions, this stage becomes diffusion-dependent, with food particle size and matrix playing pivotal roles.

Consequently, the drying processes at each of the previously mentioned stages are shaped by either the driving force, determined by energy sources, or drying diffusion, contingent on the tissue matrices of the agricultural product. Further elaboration on the former, particularly in relation to energy sources, is provided. The commonly used measure of energy efficiency is associated with the energy utilized for moisture evaporation at the material feed temperature. The overall thermal efficiency (μ) of the dryer can be assessed using Equation 1.

$$\mu = \frac{Energy\ for\ evoparation}{Total\ energy\ supplied} \qquad (1)$$

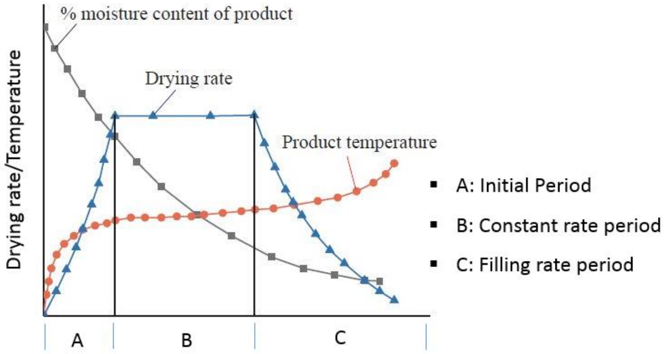

Figure. 2: Curve presents the food drying process

3.3 Limitations of paddy dryer

Circular paddy dryers, like any technology, have certain limitations. Here are some common limitations associated with circular paddy dryers:

i. Space Requirements:

Circular paddy dryers can be space-intensive, requiring a significant amount of land for installation. This may be a limitation in areas where land availability is limited or expensive.

ii. Initial Cost:

The initial cost of setting up a circular paddy dryer can be relatively high. This includes the cost of the equipment, infrastructure, and installation. This initial investment may pose a financial challenge for small-scale farmers or businesses.

iii. Energy Consumption:

Depending on the type of heat source used, circular paddy dryers may consume a considerable amount of energy. This can contribute to operating costs and environmental concerns, especially if the energy source is non-renewable.

iv. Maintenance Requirements:

Like any machinery, circular paddy dryers require regular maintenance to ensure optimal performance. Maintenance costs and the need for skilled technicians may be a concern for some users.

v. Product Quality:

Improper drying conditions or uneven airflow within the circular paddy dryer may result in uneven drying and affect the quality of the dried paddy. Achieving uniform drying is crucial for maintaining the quality of the final product.

vi. Adaptability:

Circular paddy dryers may not be suitable for all types of paddy or grains. The design and specifications of the dryer may need to be adapted based on the specific requirements of the crop being dried.

vii. Weather Dependence:

The performance of circular paddy dryers can be influenced by weather conditions, such as humidity and ambient temperature. In certain climates, these dryers may be less effective or require additional modifications.

viii. Limited Capacity:

Circular paddy dryers may have a limited capacity compared to other types of dryers. This limitation may be a concern for large-scale rice processing facilities that require higher throughput.

3.4 Future Scope of Work

Circular paddy dryers were not a specific technology. However, the specific advancements or developments in circular paddy dryers might have occurred since then.

i. Efficiency Improvements:

Future developments in circular paddy dryers may focus on improving energy efficiency, reducing drying time, and optimizing the drying process. This could involve advancements in the design of the drying chamber, the use of advanced materials, or the integration of smart control systems.

ii. Sustainability and nvironmental Impact:

There is a growing emphasis on sustainable agricultural practices. Future circular paddy dryers may incorporate features that reduce environmental impact, such as using renewable energy sources, minimizing emissions, and ensuring efficient use of resources like water.

iii. Automation and Smart Technology:

Integration of automation and smart technology can enhance the overall efficiency of paddy drying systems. This could include automated monitoring and control systems, remote sensing technologies, and data analytics to optimize the drying conditions based on real-time data.

iv. Adaptability to Climate Variability:

Given the increasing challenges posed by climate change, future paddy dryers may be designed to adapt to varying climatic conditions. This could involve incorporating climate prediction models to optimize drying parameters based on expected weather patterns.

v. Reduced Labor Dependency:

Innovations may focus on reducing the labor intensity of the drying process. Automated loading and unloading systems, as well as user-friendly interfaces, could make the operation of circular paddy dryers more accessible and efficient.

vi. Integration with Other Technologies:

Circular paddy dryers may be integrated with other technologies along the rice production value chain. For example, integration with precision agriculture, smart farming practices, or post-harvest processing technologies to create a more streamlined and connected system.

vii. Cost-Effective Solutions:

Future developments may focus on making circular paddy dryers more affordable and accessible to a wider range of farmers. This could involve innovations in manufacturing processes, materials, or the development of scalable and modular designs.

4. Conclusion

The following conclusions can be drawn after study:

- Circular paddy dryers offer advantages such as uniform drying, efficient use of space, and ease of loading and unloading.
- The design allows for a continuous and controlled drying process, contributing to the preservation of rice quality.
- Simple trained women and men can run the dryer. The 500 kg paddy can be dried in each batch in 4 to 5 hours.
- Drying efficiency is 65 to 70% and 2 to 3% moisture can be reduced per hour.

Hence, employing a paddy dryer at the farmers' and traders' level proves to be an efficient method for drying. Through field experiments, it was observed that farmers and small traders express significant interest in utilizing paddy dryers, especially during the rainy season and under cloudy weather conditions.

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