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DESIGN AND ANALYSIS OF COMPACT-AUTOMATIC PULSES DRYER

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Abstract

This paper focuses on improving the design of a grain dryer to efficiently remove moisture from grains, ensuring better storage and quality. Excessive moisture can spoil grains, making them unsuitable for long-term storage and processing. The existing dryer shows a significant temperature drop from 1100°C at the inlet to 650°C at the outlet, indicating inefficiencies. By applying heat transfer concepts and using CFX Solver and ANSYS simulations, modifications in inlet conditions and tube arrangements were explored to enhance performance. Batch-type dryers were also studied, highlighting their benefits and cost challenges. Simulation modeling has proven effective in improving grain quality and energy efficiency.

Key Words: Grain Dryer, Heat Transfer, Moisture Removal, Batch-Type Dryer, ANSYS, CFX Solver, etc

1.INTRODUCTION

India produces around 260 million tons of food grains annually, including 95 million tons of wheat, 105 million tons of rice, and 18 million tons of pulses (Anon, 2015). Due to post-harvest losses—primarily from improper drying—about 10% of this production is wasted, valued at approximately ₹2400 million. Traditional sun drying methods are slow and weather-dependent, leading to grain deterioration. Mechanical dryers, though effective, have not been widely adopted due to high costs and lack of awareness among farmers.

It discusses existing dryers, their components, and the use of simulation tools like ANSYS and CFX to optimize dryer performance. Additionally, it highlights efforts to develop affordable, small-scale dryers suitable for rural use. Focuses on improving grain drying techniques for better storage and marketability.

1.1 Components of Existing Pulses Dryer

The current dryer assembly includes ducts, hoppers, a combustion chamber, and tubes:

- Ducts transfer hot air from the dryer to the hopper.
- Hoppers store grains and facilitate drying through hot air passage.
- Combustion Chamber generates heat by burning fuels like wood or coal.
- Tubes (24 in number) transfer heat efficiently, made of galvanized iron.

The system reaches an inlet temperature of 1100°C and an outlet temperature of around 650°C.

1.2 Commercial Use of Dryers

Dryers are widely used in industries like rice milling and pulse processing to ensure proper grain storage. About 30,000 LSU-type dryers operate in India's rice industry, using heated air from rice husk combustion. Pulse milling uses both LSU-type and flat-bed dryers, critical for post-processing moisture control.

1.3 Use of Dryers at Farmer Level

Since 70% of grain production is stored by farmers, the introduction of low-cost, community-based drying centre can prevent major post-harvest losses. Dryers suited for small villages (2–4 tons/day) are essential for protecting farmer incomes and national food security.

1.4 Specific Problem and Need for Dryers

- ✓ Farmers: Heavy crop losses (e.g., 80% loss in black gram, green gram during 2002 rains) highlight the urgent need for dryers at village levels.
- ✓ Dal Mills: Solar drying is labour-intensive and slow; mechanical dryers can enhance productivity.
- ✓ Food Corporation of India: Mechanized drying can improve grain storage quality, addressing unhealthy practices of bag storage.
- ✓ Dryers are also vital across industries like textiles, plastics, chemicals, and food storage.

1.5 Limitations of the Existing System

- High initial and operating costs
- High fuel consumption
- Risk of burning grains during drying

1.6 Project Motivation

Identified limitations led to redesigning the dryer by optimizing tube dimensions to enhance heat transfer, reduce fuel consumption, and introducing compact-automation for monitoring temperature, humidity, current, and voltage.

1..7 Objectives of the Project

1. Redesign existing dryers for higher heat transfer efficiency.
2. Compact-automate the drying process and develop a control panel for real-time monitoring.

2. LITERATURE REVIEW

Mechanical drying systems provide a weather-independent solution for grain drying by controlling temperature, moisture, and humidity efficiently. Literature highlights the importance of compact-automatic hot air dryers at farmer and commercial levels for reducing post-harvest grain losses and improving storage life. Compared to imported models, locally developed dryers offer lower costs and faster drying times, especially beneficial in rural areas where electricity supply is inconsistent.
Wood and agricultural waste (white coal) are preferred fuels over diesel and electricity due to lower cost, availability, and reduced environmental impact.

Key research findings:

Sapto et al. modeled a tray dryer using SolidWorks and analyzed performance using ANSYS Fluent.

Dionissios P. Margaris et al. simulated airflow in dryers and found the *standard k-ε model* effective.

Sachin Ghanchi et al. (2013) developed a biomass-fired hot air generator achieving 47.2% efficiency.

Rumsey and Rovedo (2018) validated a dynamic model for a crossflow dryer.

Moreira and Bakker-Arkema recommended a *Pole Placement* controller for continuous grain dryers.

Abdel-Jabbar et al. improved moisture estimation using a Kalman filter.

Arinze et al. (2015) simulated in-bin barley drying under Canadian climates.

Beeny and Ngin (2018) proved that multi-pass drying improves milling yields.

Poomsa-ad et al. (2016) optimized head-rice yield through experimental and simulated studies.

Fraser and Muir (1998) suggested solar collectors could save 19–35% energy.

Harnoy and Radajewski (1986) proposed an economical drying method using alternating hot air and rest periods.

3 OVERVIEW OF EXISTING PULSES DRYERS

3.1 Methods of Grain Drying

Grain drying methods are primarily classified based on heat transfer mechanisms into:

- Conduction drying
- Convection drying (most common)
- Radiation drying

In convection drying, hot gases transfer heat to the wet grains, evaporating moisture. It can be performed in continuous or batch operations, using heated air or agricultural waste gases.

3.2 Design Procedure of Grain Dryers

Grain dryers are broadly categorized into:

3.2.1 Deep Bed Batch Dryers

- Large capacity (several hundred tonnes).
- Recommended airflow: 2.94–3.92 m^3/min/tonne.
- Grain depth limited to 2.5–3 meters based on moisture content.
- Commonly round or rectangular in shape.

3.2.2 Flat Bed Dryers

- Surface area is larger with shallower grain layers (0.6–1.2 m deep).
- Capacity: typically 1–2 tonnes.
- Advantages
  - Quick batch drying
  - Reduced risk of overdrying
  - Lower air pressure requirements

3.2.3 Continuous-Flow Batch Dryers

Grains flow vertically through a drying column two types:

- Mixing dryers: Grains are mixed using baffles; airflow: 50–95 m^3/min/tonne; temperature: ~65°C.
- Non-mixing dryers: No baffles; airflow: 125–250 m^3/min/tonne; temperature: ~54°C.

3.2.4 Grain Dryer Components

- ➢ Drying chamber
- ➢ Air distribution system
- ➢ Direct/indirect air heating system
- ➢ Blower and air filter

- Control system
- Grain conveying system

3.2.5 Key Factors in Grain Dryer Design

- Dryer Factors: Type, size, grain feed rate, airflow pattern, drying time.
- Air Factors: Air velocity, temperature, humidity, and static pressure.
- Grain Factors: Type, moisture content, latent heat of moisture evaporation.
- Heating System: Type of fuel, burner or furnace, and heat exchanger (for indirect heating).

4 PROPOSED DESIGN

4.1 Analysis and Design Improvement in Existing Pulses Dryers:

A model of the existing batch-type dryer was prepared using CATIA and analysed using ANSYS CFD.
Problems affecting system efficiency were identified, and modifications were proposed.

Key Findings:

- Effect of Tube Diameter: Reducing the tube diameter to 1.8 inches resulted in maximum outlet temperature (340.371°C), improving heat transfer compared to the existing 2.5-inch diameter.
- Effect of Number of Tubes: Keeping 24 tubes provided optimal outlet temperature. Increasing or decreasing tube numbers reduced efficiency.

Thus, the optimal setup is 24 tubes with a 1.8-inch diameter for maximum heat output.

4.2 Compact-Automation and Control Panel Design:

To reduce operational costs and manual labour, a compact-automatic control system was designed for the pulses dryer.

4.2.1 Features

- Automatic sequential operation when PB_ON automatic is pressed.
- Grain presence detection via proximity switch.
- Temperature control via PT-100 sensors:
- Blower heater off at 60°C, blower 2 turns on.
- Blower heater resumes if temperature drops to 40°C.
- Manual mode allows independent control of blowers and heaters.

4.2.2 Design Considerations

- Dryer Size and Type: Based on the daily or seasonal grain volume. Designed on thin-layer drying for continuous flow and deep bed principles for batch dryers.
- Fuel Requirement Calculation:
  Using heat balance equations:

F=qa′ηb×ηex×CnF = \frac{q'_a}{\eta_b \times \eta_{ex} \times C_n}

F=ηb×ηex×Cnqa′

Where, qa′q'_aqa′ = heat required,

η\etaη = efficiencies,

CnC_nCn = calorific value.

4.2.3 Fan and Blower Design

Centrifugal blower design based on air flow rate (Q), motor speed (N), and static pressure (P_s).

4.2.4 Bulk Density of Grains

- Paddy: 588–615 kg/m^3
- Wheat: 756–790 kg/m^3
- Corn: 721–737 kg/m^3
- Sorghum: 753 kg/m^3

4.2.5 Latent Heat of Vaporization

- Wheat: 574–629 kcal/kg
- Corn: 626–699 kcal/kg
- Sorghum: 576–626 kcal/kg

5 PROPOSED MODEL

5.1 Design Overview

A rectangular bin batch dryer is proposed for drying 1 ton of pulses at 12% (w.b.) moisture content.

5.2 Key Specifications

- Ambient Temperature: 20°C
- Relative Humidity: 75%
- Initial Moisture Content: 17%
- Final Moisture Content: 12%
- Bulk Density (at 12%): 770 kg/m^3
- Latent Heat of Vaporization: 600 kcal/kg
- Specific Heat of Grain: 0.3934 kcal/kg°C
- Dryer Dimensions:
  - ✓ Plenum chamber area: 8 × 6 ft^2
  - ✓ Dryer height: 4.75 ft

5.3Heat and Airflow Calculations:

- Moisture Evaporated: 60.209 kg
- Total Heat Utilized: 65,079 kcal/hr

- Considering 10% losses, Net Heat Required: 72,310 kcal/hr
- ✓ Plate Temperature Required: 241.11°C
- ✓ Air Supply Rate (G): 88.15 kg/min
- ✓ Air Volume Flow: 2752 CFM

5.4 Fuel Consumption and Cost

Fuel Type	Consumption	Cost per Hour	Remarks
Wood	14 kg/hr	₹98	Easily available, cleaner burn
White Coal	18 kg/hr	₹63	Eco-friendly, cost-effective
Diesel	High	₹504	Not recommended (costly, polluting)

5.5 Preferred Fuels

- ✓ Wood
- ✓ White Coal (agricultural biomass)

5.6 Cost Estimation

Particulars	Cost (₹)
Blower 5 HP Heat	20,000
Heat Exchanger	30,000
Blower 0.5 HP	10,000
Blower Motor	25,000
Dryer Structure Fabrication	50,000
Labour and Unforeseen Costs	25,000
Total Production Cost	1,60,000
Profit (20%) Added	Selling Price: 2,00,000

6 RESULT AND ANALYSIS

Hardware Overview:

The compact-automatic pulses dryer was developed and assembled. (See Figure: Photograph of Overall 3D Model of Pulses Dryer.)

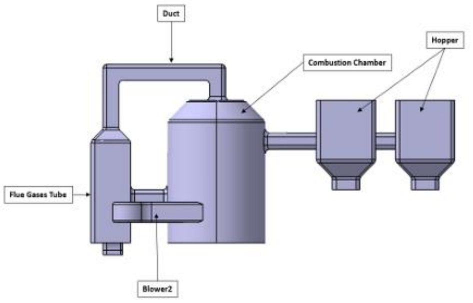
6.1 Drying Performance Testing

Table #1: Grain Weight Variation During Drying

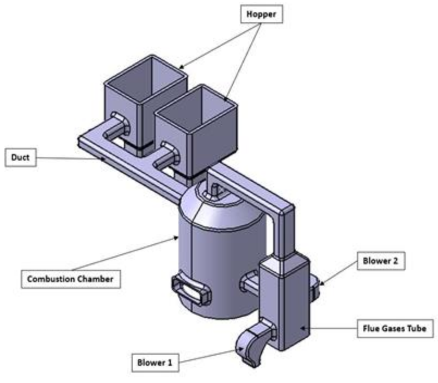
Time (minutes)	Grain Weight (g)
0	1000
10	980
20	977
30	970
40	960
50	957
60	951
70	937
80	933
90	927

Table #2: Water Content Variation During Drying

Time (minutes)	Water Content (%)
0	18
10	18
20	17.5
30	16.5
40	16
50	15.5
60	14.5
70	13.5
80	13
90	12.5



Back View



Isometric View

Figure #1: Photograph of Overall 3D Model of Pulses Dryer

6.2 Key Observations

- First 10 minutes: Weight decreased by 20g, no moisture reduction.
- 20 minutes: Moisture content reduced by 0.5%, slight weight loss (3g).
- 30–90 minutes: Steady decrease in both moisture content and weight. Final water content reduced to 12.5% and weight to 927g after 90 minutes.

7. CONCLUSIONS

The analysis confirms that the modified dryer design is optimal for improving heat transfer efficiency. Changing the tube diameter from 2.5 inches to 1.8 inches resulted in a temperature increase of 0.414°C (0.17%), enhancing system performance.

The compact-automatic pulses dryer provides efficient and clean drying, making it a viable alternative to traditional sun drying methods, especially under unpredictable weather conditions.

7.1 Precautions to Be Taken

- Install high-efficiency gas cleaning systems due to powder emissions.
- Use superheated steam to dry toxic materials safely if needed.
- Drying lumped or difficult-to-disperse materials may not be feasible.
- Fire and explosion risks exist; proper safety measures must be followed.
- Residence time variations in the dryer must be monitored, especially with material recirculation.

7.2 Future Scope

- Develop fully automated dryers with features like automatic temperature control, moisture sensing, and fuel feeding.
- Design and fabricate large-capacity dryers (200 metric tons) for bulk storage facilities like FCI.
- Design compact mini dryers (200–300 kg capacity) for individual farmers, promoting decentralized grain drying.

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