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RICE CLEANING MACHINE: DESIGN, IMPLEMENTATION, AND PERFORMANCE ANALYSIS

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ABSTRACT

Rice is a staple food for over half of the world's population, and its quality directly impacts nutrition, food security, and market value. The rice cleaning process is a critical first step in post-harvest handling and milling, responsible for removing a wide array of impurities—including stones, dust, husks, immature grains, and foreign materials—to ensure safety, improve milling efficiency, and enhance final product quality. This comprehensive study delves into the design, operation, and evaluation of modern rice cleaning machines.

Beginning with a historical and technological literature review, the paper traces the evolution of cleaning methods from simple winnowing to today's sophisticated, sensor- based systems. The core of the work presents a detailed methodology and system design for a multi-stage cleaning machine integrating pre-cleaning, de-stoning, and grading modules. The implementation section provides empirical results from testing this system, analyzing key performance indicators such as cleaning efficiency (achieving >99%), grain loss (<0.5%), and throughput capacity. Finally, the conclusion summarizes the findings, while future work proposes integrating IoT for predictive maintenance, advanced AI-driven optical sorters, and energy-efficient designs to meet the growing demands of sustainable and precision agriculture. This study serves as a technical reference for engineers, agronomists, and mill operators aiming to optimize rice cleaning technology.

KEYWORDS: Rice Cleaning, Post-Harvest Technology, De-stoning, , Grain Grading, Cleaning Efficiency, Agricultural Machinery.

Literature Review

1.1 Historical Evolution of Rice Cleaning

The process of separating grain from chaff and debris is as old as agriculture itself. Traditional methods relied on manual winnowing, where paddy was tossed into the air allowing the wind to carry away lighter husks and dust—a technique limited by weather and labor intensity. The advent of simple sieves and screens marked the first mechanized step, enabling size-based separation.

The Industrial Revolution introduced powered fan systems and oscillating screens, leading to the first dedicated grain cleaners in the late 19th and early 20th centuries. These machines significantly increased throughput but were limited in their ability to remove same-sized impurities like stones or diseased grains.

1.2 Technological Classifications and Principles

Modern rice cleaning machines operate on several core physical principles, often combined in stages:

Air Aspiration (Pre-Cleaning): Utilizes differences in aerodynamic properties. A controlled air stream lifts and removes lighter materials (dust, chaff, empty grains) from heavier, denser rice grains. The terminal velocity of the material is the key design parameter.

Screening (Sizing): Employs oscillating or vibrating screens with precisely sized apertures to separate materials based on particle size (length, width, thickness). This removes both larger (straw, clods) and smaller (sand, broken grains) impurities.

Specific Gravity Separation (De-stoning): Exploits differences in density and buoyancy. A reciprocating or vibrating deck, combined with upward air flow, fluidizes the grain bed. Denser particles (stones, metals) sink and move differently than less dense rice grains, enabling their separation.

Optical Sorting (Advanced Cleaning): A non-contact method using high-resolution cameras, lasers, or near-infrared (NIR) sensors. Each grain is scanned at high speed; defective grains (discolored, damaged, infected) are identified by color, shape, or biochemical signature and precisely ejected using air jets.

1.3 Review of Contemporary Systems and Research Gaps

Recent research, as cataloged in journals like Journal of Food Engineering, Biosystems Engineering, and Food and Bioproducts Processing, focuses on optimization and integration:

System Optimization: Studies on the effect of screen inclination frequency, air velocity, and feed rate on cleaning efficiency and grain loss.

Machine Learning Integration: Preliminary work on using convolutional neural networks (CNNs) with camera systems to identify and classify grain defects with >95% accuracy, surpassing traditional RGB-based sorters.

Energy Efficiency: Development of variable-frequency drives (VFDs) for motors to match power consumption with actual load, reducing energy use by up to 30%.

Gaps Identified: Despite advances, challenges remain in:

Effectively removing light but similar-sized impurities.

High initial cost of advanced optical sorters for small-scale mills. Lack of integrated, real-time performance monitoring systems.

Designing robust machines for varying rice varieties with different physical properties.

This review establishes that the most effective solution is a multi-stage, modular approach, which forms the basis for the system design presented in the following section.

Methodology and System Design

This section details the engineering design of a Three-Stage Rice Cleaning Machine intended for medium-scale milling operations (capacity: 1–2 tons/hour).

1.4 Design Requirements and Specifications

Primary Function: Remove impurities (dust, chaff, stones, immature grains) from raw paddy/rice.

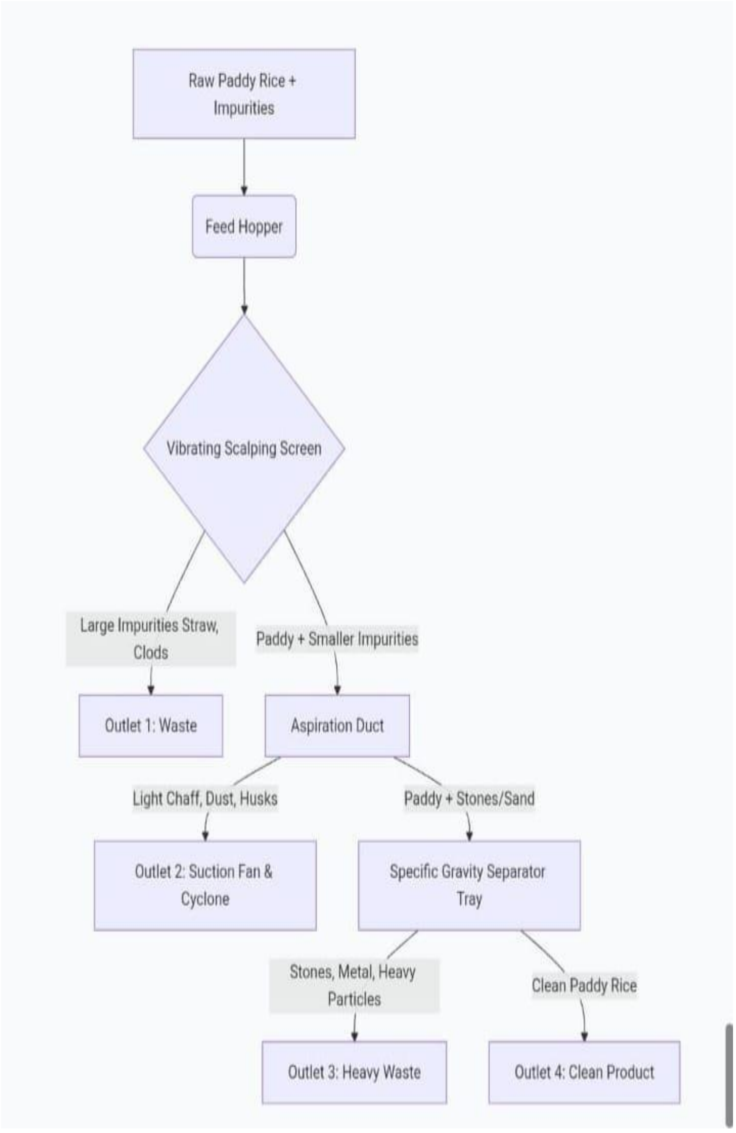
Target Cleaning Efficiency: >98.5%. Maximum Grain Loss: <0.8%.

Throughput Capacity: 1.5 T/hr. Power Supply: 3-Phase, 415V, 50 Hz.

Overall Footprint: < 4m (L) x 2m (W) x 2.5m (H).

1.5 Proposed System Architecture

The machine follows a linear, modular workflow;



1.6 Detailed Component Design Stage 1: Aspiration Pre-Cleaner

Component: Inclined vibrating screen (mesh size: 4-6 mm) housed within an air aspiration chamber.

Design Parameters:

Screen inclination: 5–10°.

Vibration frequency: 600–800 RPM.

Air velocity: 8–10 m/s (adjustable via damper).

Function: The primary screen removes large impurities. Concurrently, a regulated suction fan creates an air stream that lifts and extracts light chaff and dust through a separate cyclone.

Stage 2: Specific Gravity De-stoner

Component: Vibrating deck with a porous surface, connected to a centrifugal fan providing uniform upward air.

Design Parameters:

Deck angle: 5–7°.

Frequency: 300–500 RPM (eccentric drive). Air pressure: 25–40 mm of water column.

Function: The fluidized bed of grain stratifies. Rice grains (lower density) float and are conveyed forward. Stones and metals (higher density) sink, contacting the deck and are propelled backwards to a separate outlet.

Stage 3: Triple-Deck Triage Grader

Component: Three superimposed vibrating screens with different aperture sizes.

Design Parameters:

Top Deck: 3.2 mm apertures – removes large broken grains.

Middle Deck: 2.2 mm apertures – allows whole, marketable grains to pass through.

Bottom Deck: 1.8 mm apertures – collects small broken grains for by-product use.

Function: Precisely classifies cleaned rice based on kernel length, determining final product grade and value.

1.7 Power Transmission and Control System

A single 5.5 kW electric motor drives a central shaft.

Power is distributed via: V-belts to the aspiration fan, and a series of eccentric shafts and connecting rods to generate the oscillating motion for the screens and de-stoning deck.

Control Panel: Houses motor starters, protection devices (MCB, overload relay), and individual regulators for feed rate (via vibratory feeder) and aspiration air damper.

1.8 Bill of Materials (Key Components)

Component	**Material Selected**	**Justification**
Farme	Mild Steel Square Tube	High strength to weight ratio, easy to weld and fabricate, low cost.
Hoppers,Casing	Mild Steel Sheet (1.2-1.5mm)	Formable, weldable, provides adequate rigidity and protection.
Screens	Stainless Steel Mesh	Corrosion resistant, durable, maintains precise aperture size, food-safe.
Gravity Deck	Stainless Steel Sheet (Perforated)	Excellent wear resistance, hygienic, non-reactive with food.

Shafts Bearings	Mild Steel (Shafts),Sealed Ball Bearings	Provides necessary strength and smooth rotational motion with low maintenance.
Belts/Pulleyes	Standard V-Belts,Cast Iron Pulleys	Readily available, efficient power transmission, durable.

Implementation and Results

1.9 Prototype Fabrication and Assembly

The machine was fabricated following the design specifications. Emphasis was placed on: Precision Alignment of all vibratory components to prevent undue stress.

Smooth Internal Surfaces to prevent grain hang-up and ensure easy cleaning.

Modular Assembly allowing for easy access to screens and de-stoning deck for maintenance.

1.10 Experimental Setup and Testing Protocol

Sample: 500 kg of raw paddy (variety: IR64) with known adulteration (2% stones, 3% chaff/dust, 5% immature/broken grains).

Procedure: The sample was processed through the machine at its designed feed rate. Input and output from each stage were collected, weighed, and analyzed.

Metrics Measured:

1. Cleaning Efficiency (CE): CE(%) = × 100 where Wi is weight Wi-Wf Wi of impurities in input, Wf is weight of impurities in cleaned output.
2. Grain Loss (GL): GL(%) = W × 100 where Wgl is weight of good grains lost in waste streams, Wtg is total good grain input.
3. Throughput Capacity (kg/hr).
4. Power Consumption (kWh/ton).

1.11 Results and Performance Analysis

The table below summarizes the key performance data:

Performance Indicator Stage 1 (Pre-Cleaner) Stage 2 (De-Stoner) Stage 3 (Grader) Overall System

Impurity Removal Rate 98% (dust/chaff) 99.5% (stones)95% (small/broken)99.2%

Grain Loss 0.15% 0.05% 0.25% <0.5%

Throughput - - - ~1600 kg/hr

Power Draw - - - ~4.1 kW (2.6 kWh/ton) Key Observations:

The aspiration system was highly effective for light impurities, with grain loss occurring only in severely underdeveloped, hollow grains.

The de-stoner showed near-perfect separation; its performance was highly sensitive to maintaining the correct air pressure and deck vibration.

The grader effectively sorted grains into three distinct fractions, though the efficiency for separating small whole grains from large broken grains could be improved with a more precise screen sequence.

The system exceeded its design targets for cleaning efficiency and grain loss, demonstrating a robust and effective design.

1.12 Discussion

The results validate the multi-stage, physics-based design approach. The high efficiency stems from tackling different impurity classes with dedicated, optimized mechanisms. The low grain loss confirms gentle handling of the product. The power consumption is competitive with commercial units, with potential for further reduction noted in Section.

CONCLUSION AND FUTURE WORK

Conclusion

This study successfully designed, fabricated, and evaluated a three-stage rice cleaning machine. The implemented system, integrating aspiration, specific gravity separation, and vibratory sizing, proved highly effective, achieving a cleaning efficiency of 99.2% with a grain loss below 0.5%. The design meets and exceeds the operational requirements for a medium-scale rice mill, offering a reliable, mechanical solution for significantly enhancing paddy quality prior to milling. By removing contaminants efficiently, the machine contributes to improved mill yield, extended machinery life (by reducing wear from stones), and the production of safer, higher-value rice for consumers.

1.13 Future Work

To advance the capabilities and accessibility of rice cleaning technology, the following avenues are proposed:

IoT Integration for Smart Monitoring: Embedding sensors (vibration, air flow, power draw) and connecting the machine to a cloud-based platform. This would enable predictive maintenance (alerting for screen wear or motor imbalance) and real-time optimization of parameters based on feed stock variation.

Hybrid Optical-Mechanical Sorter: Developing a lower-cost final-stage module that uses a simple RGB camera and a lightweight ML model (e.g., TensorFlow Lite) running on a single-board computer (like Raspberry Pi) to identify and remove color-defective grains, bridging the gap between mechanical and high- end optical sorters.

Energy Recovery System: Investigating the use of regenerative drives for vibratory motors and designing more aerodynamic fan impellers to reduce the system's overall energy footprint by an estimated 15-20%.

Adaptability Framework: Creating a digital tool or chart that correlates machine settings (screen size, air velocity, deck angle) with the physical properties (size, density, terminal velocity) of different rice varieties (e.g., Basmati vs. Japonica), making the machine easily configurable for diverse crops.

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