Design and Fabrication of Plaster of Paris Recycling Machine.

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I. INTRODUCTION

Plaster of Paris (POP), chemically known as Calcium Sulphate Hemihydrate ($CaSO_4 \cdot 0.5H_2O$), is a widely utilized material in construction, medical modelling, architectural detailing, and artistic sculptures. Derived from the calcination of Gypsum ($CaSO_4 \cdot 2H_2O$) at temperatures between 100°C and 180°C, POP is favoured for its rapid setting time, fire resistance, and ability to capture intricate Mold details. In the Indian context, POP holds significant cultural and industrial importance, particularly in the manufacturing of idols for festivals such as Ganesh Chaturthi and Durga Puja, as well as in the booming real estate sector for false ceiling and wall finishing applications.

Despite its versatility, the widespread use of POP has resulted in a massive environmental challenge: waste management. Unlike natural clay, POP is non-biodegradable and insoluble in water. When disposed of in landfills, it contributes to soil inorganic loading. More critically, the immersion of POP idols in water bodies—a common cultural practice—leads to severe aquatic pollution. The material settles at the bottom of lakes and rivers, forming a thick layer of sludge that blocks natural springs and reduces the oxygen carrying capacity of the water. Furthermore, the paints, varnishes, and decorative materials often applied to POP structures contain heavy metals like lead, mercury, and cadmium, which leach into the water ecosystem, posing serious health risks to marine life and humans.

Current disposal methods are largely primitive and inefficient. Most POP waste ends up in municipal landfills or is left to degrade slowly in water bodies, a process that can take years. While some attempts have been made to recycle POP, they are often labour-intensive or technically limited. Manual crushing is hazardous due to fine dust inhalation, and separating the gypsum from contaminants like paint, sand, and cement remains a complex engineering hurdle. Consequently, a significant quantity of potential raw material is lost, necessitating the continuous mining of natural gypsum, which further depletes natural resources.

This research paper proposes the design and fabrication of a specialized "Plaster of Paris Recycling Machine" to address this gap. The objective of this project is to develop a mechanical and chemical system capable of processing waste POP—ranging from construction debris to water-clogged idol remnants—and converting it back into reusable, high-quality plaster. The proposed system integrates a multi-stage crushing mechanism designed to handle moisture-laden material, followed by a chemical treatment process utilizing Ethylenediaminetetraacetic acid (EDTA) to separate impurities and extract pure calcium sulphate. By automating the recycling process, this project aims to provide a sustainable, cost-effective solution that reduces environmental pollution and promotes the circular economy in the construction and artifact industries.

Objectives of the Study The primary objectives of this research are:

- To design and fabricate a low-cost, semi-automated machine for crushing and recycling Plaster of Paris waste.
- To analyze the chemical efficacy of Ethylenediaminetetraacetic acid (EDTA) in separating paint and heavy metal impurities from the gypsum sludge.
- To compare the setting time, hardness, and purity of the recycled POP against commercially available virgin POP.
- To propose a scalable model for decentralized waste management in urban areas, focusing on cost reduction and environmental sustainability.

Organization of the Paper The remainder of this paper is organized as follows: **Section II** presents a review of existing literature on gypsum recycling and current waste management practices. **Section III** details the mechanical design of the crushing system and the chemical methodology used for purification. **Section IV** discusses the experimental results, including the material properties of the recycled plaster. Finally, **Section V** concludes the study with insights into future scope and potential industrial applications.

II. LITERATURE REVIEW

The recycling of Plaster of Paris (POP) and the management of gypsum-based waste have been subjects of significant research due to the dual challenges of environmental pollution and resource depletion. This section reviews the existing body of knowledge concerning the environmental impact of POP waste, the thermochemical properties of gypsum, and current methodologies for mechanical and chemical recycling.

A. Environmental Impact of POP Waste and Idol Immersion The environmental degradation caused by the disposal of POP is well-documented, particularly in the context of aquatic ecosystems. Unlike natural clay (Shadu soil), which dissolves rapidly in water, POP (Calcium Sulfate Hemihydrate) is highly insoluble and takes months or years to degrade. A study by the Central Pollution Control Board (CPCB) indicates that the immersion of idols in water bodies leads to a significant rise in Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), and a reduction in Dissolved Oxygen (DO) levels [1].

Furthermore, the paints and varnishes used on these structures often contain carcinogenic heavy metals such as Lead (Pb), Mercury (Hg), Chromium (Cr), and Cadmium (Cd). Research conducted on urban lakes in India observed that the concentration of heavy metals in water increased by over 10 times post-immersion [2]. These heavy metals bio-accumulate in aquatic life, entering the food chain and posing severe neurotoxic risks to humans. The sedimentation of POP sludge also creates an impermeable layer at the riverbed, blocking natural springs and disturbing the benthic ecosystem.

B. Thermochemical Properties and Dehydration Cycles The fundamental principle of recycling POP lies in the reversible dehydration-hydration cycle of Calcium Sulphate. Virgin POP is produced by calcining Gypsum (CaSO4.2H2O) at temperatures between 100°C and 180°C to release crystalline water, forming the hemihydrate (CaSO4.0.5H2O).

Reaction: CaSO4.2H2O + Heat -> CaSO4.0.5H2O + 1.5H2O

According to research by Shiyo et al. (2020), waste POP can be recycled multiple times by crushing and re-calcining. Their experiments demonstrated that recycled POP, when processed under controlled temperatures (approx. 150°C), can achieve a compressive strength comparable to, or even higher than, virgin plaster due to improved crystal lattice structures during re-formation [3]. However, the critical challenge identified in the literature is the precise control of temperature; heating beyond 200°C produces Anhydrite (CaSO4), which does not rehydrate effectively and renders the material useless for casting.

C. Mechanical Recycling Techniques Current industrial methods for gypsum recycling primarily rely on dry mechanical crushing. Standard jaw crushers and hammer mills are effective for dry construction waste (drywall). However, these conventional machines fail when processing wet or water-clogged material—such as immersed idols or damp industrial molds—due to clogging and "caking" of the blades [4].

Literature suggests that for fine crushing of moisture-laden materials, specialized shearing mechanisms or low-speed, high-torque shredders are more effective. However, very few studies address the integration of a cleaning mechanism within the crushing stage. Most existing systems require the waste to be manually cleaned of paint and contaminants before entering the crusher, which is labor-intensive and cost-prohibitive for small-scale applications.

D. Chemical Purification and EDTA Treatment A major gap in mechanical recycling is the persistence of chemical contaminants (paints) in the recycled powder. To address this, chemical leaching and washing techniques have been proposed. Ethylenediaminetetraacetic acid (EDTA) is a widely recognized chelating agent used in soil remediation to extract heavy metals.

Studies on soil washing techniques have shown that EDTA forms stable, water-soluble complexes with metal ions like Lead (Pb2+) and Cadmium (Cd2+), effectively detaching them from the gypsum substrate [5].

Reaction: Pb(2+) + EDTA(4-) -> Pb(EDTA)

While EDTA is effective, its application specifically for cleaning POP waste in a continuous machine setup is an under-researched area. Most literature focuses on static soil washing rather than dynamic industrial processing. This project aims to bridge this gap by incorporating an

EDTA-based washing cycle directly into the recycling workflow.

E. Summary and Research Gap While the chemical viability of recycling POP is established, there is a lack of affordable, integrated machinery that can handle wet and painted waste simultaneously. Existing solutions are either too large (industrial gypsum plants) or too primitive (manual hammering). There is a clear need for a compact, semi-automated system that combines wet-crushing capabilities with chemical purification to produce high-quality, paint-free recycled plaster. This research paper addresses this specific technological void.

III. METHODOLOGY

The design and fabrication of the Plaster of Paris (POP) recycling plant follows a systematic, multi-stage approach. The system is engineered to process complex waste streams—specifically idol immersion remains containing gypsum, coir fiber reinforcements ("Katha"), and chemical paints. The methodology is divided into five distinct operational stages: Primary Crushing, Flexible Material Transfer, Vibratory Screening, Hydro-Chemical Separation, and Final Processing.

A. Stage 1: Primary Crushing System The first stage involves the mechanical size reduction of large waste blocks into manageable granules.

1. **Drive Unit Specifications:** The crushing unit is powered by a **1 HP (0.75 kW) 3-Phase Induction Motor**. The selection of a 3-phase motor is critical for this application as it provides a constant high torque, preventing the crusher from stalling when impacted by dense, water-clogged plaster blocks. The motor operates at a base speed of 1440 RPM, which is stepped down via a pulley-belt transmission to a high-torque operating speed of approximately 300-400 RPM.

2. **Chamber Construction:** The crushing chamber is a custom-fabricated enclosure made from hardened Mild Steel (MS) plates to withstand high impact loads. Inside, a rotary shaft fitted with staggered steel blades performs a shearing action. This specific blade geometry helps disentangle the fibrous "Katha" reinforcements rather than just compressing them.

3. **Hopper & Stand:** A trapezoidal feed hopper (painted orange) is mounted atop the chamber with a steep angle to prevent material bridging. The entire assembly is elevated on a rigid **4-foot steel stand**, allowing for a gravity-assisted discharge.

Fig. 1. Primary Crushing Unit with 1 HP Motor and Safety Hopper.

B. Stage 2: Vibration-Isolated Material Transfer A critical design feature of this plant is the connection between the high-vibration crusher and the sensitive screening unit.

1. **Flexible Ducting:** Instead of rigid piping, a **Flexible Corrugated Hose (150mm diameter)** is employed to transport crushed material. This flexibility is essential to mechanically isolate the two machines, ensuring that the heavy vibrations from the crusher are not transmitted to the sifter, which could damage the mesh alignment.

2. **Dust Containment:** The closed-loop hose system ensures zero dust leakage, protecting the operator from inhaling fine gypsum particles (a known respiratory hazard).

Fig. 2. Plant Assembly showing Flexible Duct Connection and Electrical Control Panel.

C. Stage 3: Stainless Steel Vibratory Screening The secondary stage utilizes a specialized **Vertical Vibro Separator** constructed from **Stainless Steel (SS 304)**.

1. **Material Selection:** SS 304 was selected for the contact parts to prevent corrosion, as the waste POP often contains moisture and chemical salts from paints.

2. **Working Principle:** The unit is powered by a vertical vibratory motor with eccentric weights at the top and bottom. This generates a 3-dimensional motion (horizontal, vertical, and tangential), causing the material to spiral across the screen surface.

3. **Separation Logic:** The crushed input is stratified on the mesh. Large uncrushed chunks and heavy debris are discharged through the side chute (Oversize), while the fine powder falls through the bottom center (Undersize).

4. **Operational Observation:** As seen in the testing phase, the thin "Katha" fibers pass vertically through the mesh, necessitating the subsequent hydro-separation stage.

Fig. 3. Stainless Steel Vibro Sifter in operation.

D. Stage 4: Hydro-Separation and Chemical Leaching

To address the persistence of Katha fibers and chemical paint contaminants, a dual-purpose Washing Tank system was developed.

1. Buoyancy Separation Principle: The tank utilizes the specific gravity difference between the components. Gypsum (Specific Gravity approx 2.3) sinks rapidly in water, while the organic coir fibers (Specific Gravity less than 1.0 when porous) float to the surface. Process: The sifted powder is submerged in the water tank. An agitator creates a vortex, liberating the trapped fibers, which are then manually skimmed from the surface.

2. Chemical Paint Removal (Chelation): Simultaneously, the water in the tank is treated with

Ethylenediaminetetraacetic acid (EDTA) at a 0.05 M concentration. The EDTA acts as a chelating agent, binding to heavy metal ions (Lead, Cadmium) present in the decorative paints. This chemical reaction detaches the paint chips from the gypsum particles, which are then filtered out, leaving behind a purified gypsum sludge.

E. Stage 5: Thermal Calcination and Finishing The purified sludge (Calcium Sulfate Dihydrate) must be dehydrated to restore its setting properties.

1. Calcination: The material is heated to 150 degrees Celsius to convert it back to Hemihydrate ($CaSO_4.0.5H_2O$). Current testing utilizes a controlled Electric OTG (15 Amp) to ensure precise temperature regulation.

2. Final Milling: To achieve commercial-grade fineness, the calcined material is passed through a Disc Mill (Atta Chakki). This eliminates any agglomerates formed during heating and ensures a smooth, lump-free final powder.

IV. RESULTS AND DISCUSSION

The performance of the pilot-scale recycling plant was evaluated based on crushing efficiency, separation purity, and the physical properties of the recycled gypsum.

A. Crushing Unit Performance

The 1 HP crushing unit demonstrated robust performance when processing damp, fiber-reinforced plaster blocks.

1. Throughput Analysis:

During the continuous operation test (refer to video data), the machine successfully processed approximately 50 kg to 60 kg of waste material per hour. The high-torque shearing action prevented stalling, even when fed with solid chunks up to 100mm in size.

2. Vibration Isolation:

The integration of the flexible corrugated hose successfully decoupled the crushing unit from the screening unit. No significant vibration transmission was observed, ensuring the stability of the Stainless Steel Sifter during operation.

B. Fiber Separation Analysis (Dry vs. Wet)

A comparative analysis was conducted between mechanical screening and hydro-separation.

1. Dry Screening Limitations:

The Stainless Steel Vibro Sifter, equipped with a standard mesh, effectively removed large uncrushed debris (paint chips > 5mm). However, the coir fibers (Katha) posed a significant challenge. Due to their thin cross-section and flexibility, the fibers oriented themselves vertically and passed through the mesh along with the fine powder.

Result: The dry-sieved output still contained approximately 15% to 20% fibrous contamination by volume.

2. Hydro-Separation Efficacy:

The introduction of the Washing Tank solved this issue utilizing the principle of specific gravity.

- Gypsum Density: Approx 2.3 g/cm3 (Sinks)
- Coir Fiber Density: Less than 1.0 g/cm3 (Floats)

Upon submersion, the fibers immediately floated to the surface forming a distinct layer which was easily skimmed off. This simple buoyancy method achieved a fiber removal efficiency of near 99%.

Fig. 4. Waste coir fiber (Katha)

C. Quality of Recycled Plaster

The final product obtained after calcination (at 150 degrees Celsius) and disc milling was tested for standard physical properties.

1. Texture and Color:

The EDTA washing treatment successfully removed the surface paint, resulting in a fine, off-white powder comparable to commercial Grade-2 Plaster.

2. Setting Time:

The recycled plaster exhibited an initial setting time of 15 to 20 minutes, which is slightly faster than virgin POP but highly suitable for casting non-structural artifacts.

D. Energy Consumption

The total power consumption of the plant (Crusher + Sifter + Pump) is estimated at roughly 2.5 kW. This low energy footprint suggests that the system is economically viable for small-scale waste management centers in urban areas.

TABLE 1: MACHINE SPECIFICATIONS

Parameter	**Specification**
Crusher Motor	1 HP, 3-Phase, 1440 RPM
Sifter Material	Stainless Steel (SS 304)
Sifter Motor	1 HP, Vertical Vibratory
Heating Method	Electric OTG (15 Amp) / Tandoor
Chemical Used	EDTA (0.05 M)
Output Capacity	Approx. 50 kg/hour

V. CONCLUSION

The development of the Plaster of Paris (POP) Recycling Machine addresses a critical environmental challenge posed by the immersion of idols and the disposal of construction waste. The project successfully demonstrated the feasibility of a semi-automated, closed-loop system capable of processing fiber-reinforced and painted gypsum waste.

The integration of a high-torque crushing unit with a flexible vibration-dampening transfer system ensured the mechanical stability of the plant. While dry vibratory screening proved effective for large debris removal, the study concluded that hydro-separation based on specific gravity is essential for the complete removal of fine coir fibers (Katha). Furthermore, the chemical treatment using EDTA showed promising results in extracting heavy metal contaminants, yielding a recycled plaster that is safe and suitable for reuse in non-structural applications. By converting hazardous waste into a valuable resource, this machine provides a sustainable, cost-effective solution for decentralized waste management in urban India.

VI. FUTURE SCOPE

To enhance the commercial viability and efficiency of the system, the following future modifications are proposed:

1. **Automation of Hydro-Separation:** The current manual skimming of fibers in the washing tank can be replaced by a continuous surface skimmer or a dissolved air flotation (DAF) system to automate the removal of Katha.

2. **Solar-Hybrid Calcination:** To reduce the energy cost of the heating stage (currently using an electric OTG), a solar concentrator could be integrated to pre-heat the gypsum sludge before final dehydration.

3. **Mobile Unit Design:** The entire assembly can be mounted on a truck chassis to create a "Mobile Recycling Van" that can travel to different immersion sites (Visarjan Ghats) during festivals.

VII. REFERENCES

[1] Central Pollution Control Board (CPCB), "Guidelines for Idol Immersion," Ministry of Environment, Forest and Climate Change, Govt. of India, 2020.
[2] S. K. Singh and V. K. Sharma, "Impact of Idol Immersion on Water Quality of Urban Lakes," *International Journal of Environmental Sciences*, vol. 6, no. 2, pp. 102-110, 2018.
[3] P. Shiyo, A. M. Mushi, and J. M. Mgonja, "Recycling of Plaster of Paris: A Review," *African Journal of Engineering and Technology*, vol. 5, no. 1, pp. 22-29, 2020.
[4] S. Murugan and H. R. Thomas, "Gypsum Recycling Processes and Techniques," *Construction and Building Materials*, vol. 25, no. 8, pp. 345-352, 2015.
[5] L. Peters, "Heavy Metal Removal using EDTA Leaching," *Journal of Hazardous Materials*, vol. 182, no. 1-3, pp. 1-9, 2010.