International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

Design of a Compact Smart Waste Neutralization System for Small and Medium Electroplating Enterprises

Shakthivel M R
Department of Mechanical and Mechatronics Engineering
(Additive Manufacturing)
Coimbatore, India

Velayutham V
Department of Mechanical and Mechatronics Engineering
(Additive Manufacturing)
SNS College of Engineering
Coimbatore, India

Santhosh N
Department of Mechanical and Mechatronics Engineering
(Additive Manufacturing)
SNS College of Engineering
Coimbatore, India

Ishaan H Shah
Department of Mechanical and Mechatronics Engineering
(Additive Manufacturing)
SNS College of Engineering
Coimbatore, India

Vishal Ruban A J
Department of Mechanical and Mechatronics Engineering
(Additive Manufacturing)
SNS College of Engineering
Coimbatore, India

Gowthem M
Department of Mechanical and Mechatronics Engineering
(Additive Manufacturing)
SNS College of Engineering
Coimbatore, India

Abstract—Electroplating industries generate wastewater containing acidic residues, dissolved metals, and suspended impurities that require neutralization before safe discharge. Conventional effluent treatment plants are generally designed for larger industries and are often difficult for small and medium enterprises (SMEs) to adopt because of higher cost, greater space demand, and operational complexity. This paper presents the design of a compact smart waste neutralization system intended for SME electroplating units. The proposed system integrates a collection tank, treatment tank, neutralizing-agent tank, pH sensing, level monitoring, automated dosing, and agitation-assisted mixing under microcontroller-based control. The study focuses on system architecture, control logic, and design suitability for decentralized wastewater handling. By emphasizing compactness, process simplicity, and reduced manual intervention, the proposed design offers a practical approach for improving neutralization consistency in small-scale industrial environments. The work contributes a control-oriented and application-focused framework that can support future development of affordable wastewater neutralization solutions for SME electroplating sectors.

Keywords—electroplating wastewater, pH neutralization, SMEs, automated dosing, compact treatment system

I. INTRODUCTION

Electroplating and surface-finishing operations generate wastewater containing acidic or alkaline residues, dissolved metal ions, process chemicals, and suspended contaminants. If this effluent is discharged without treatment, it can contribute to corrosion, environmental degradation, and non-compliance with discharge regulations. As environmental responsibility and discharge regulation become increasingly important in industrial practice, even small-scale units must adopt safer and more consistent wastewater-handling methods.

Large industries generally employ full-scale effluent treatment plants for wastewater conditioning and neutralization. However, such systems are often unsuitable for small and medium enterprises because they require higher capital investment, larger installation area, and trained supervision. In many smaller units, neutralization continues to be carried out manually, which can result in inconsistent pH correction, higher chemical consumption, poor repeatability, and increased operator exposure to treatment chemicals.

The challenge in SME wastewater treatment is therefore not limited to treatment capability alone. A suitable system must also be compact, understandable, operationally manageable, and capable of providing dependable neutralization without the complexity associated with large treatment infrastructure. These conditions create a clear need for a decentralized neutralization-oriented solution designed specifically for smaller industrial settings.

The novelty of the present work lies in proposing an SME-oriented smart neutralization architecture that integrates

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

collection, sensing, controlled dosing, agitation, and settling within a compact decentralized treatment concept. The present work addresses this need by proposing a compact smart waste neutralization system that combines simple tank architecture with sensor-assisted dosing and agitation-based mixing for improved pH control in SME electroplating environments.

II. LITERATURE REVIEW AND RESEARCH GAP

Electroplating wastewater treatment has been studied through chemical neutralization, precipitation, electrocoagulation, membrane separation, adsorption, and hybrid treatment processes. Among these approaches, pH correction remains a critical first step because it influences discharge safety, downstream handling, and the precipitation behavior of metal-bearing contaminants. In most treatment schemes, effective neutralization is essential before other stages can operate efficiently.

Electrocoagulation and membrane-based systems offer strong pollutant-removal capability, especially for dissolved metals and recovery-oriented applications. However, these methods generally require additional infrastructure, higher energy input, clarification arrangements, or stricter maintenance control. Their direct adoption in small decentralized units is therefore limited, particularly where wastewater volume is moderate and economic constraints are significant.

Recent studies on automated pH control highlight the importance of real-time sensing, controlled reagent addition, and feedback-based operation. Such approaches improve process repeatability, reduce chemical overdosing, and minimize dependence on operator judgment. These findings support the development of compact automated neutralization systems for smaller industries, where limited automation can significantly enhance treatment consistency.

Despite these developments, relatively limited academic attention has been given to SME-oriented wastewater neutralization designs that prioritize compactness, process simplicity, and practical integration over multistage treatment complexity. Most reported systems are either designed for larger installations or focus primarily on pollutant-removal performance without addressing the operational realities of small enterprises.

Accordingly, the research gap addressed in this paper lies in the design of a compact, control-oriented neutralization system intended specifically for small and medium electroplating enterprises. The contribution of the present work is a practical design framework that combines a three-tank layout, pH sensing, level-based sequencing, automated dosing, and agitation-assisted mixing in a form suited for decentralized industrial use.

III. PROPOSED SYSTEM DESIGN

The proposed system follows a compact three-tank arrangement consisting of a wastewater collection tank, a main treatment tank, and a neutralizing-agent tank. Wastewater generated from electroplating-related operations is first collected and then transferred to the treatment chamber. A level-based arrangement is used to limit filling to the required working volume, thereby improving process control and preventing unnecessary overflow or irregular operation.

The treatment tank serves as the core neutralization chamber. A pH sensor continuously monitors the condition of the wastewater, and the measured signal is processed by a microcontroller-based control unit. When the pH falls outside the desired operating range, the dosing arrangement introduces neutralizing reagent in a controlled manner. This approach reduces the uncertainty associated with manual chemical addition and improves consistency in pH adjustment.

An air-agitation line is included to improve mixing within the treatment chamber. Uniform mixing is important because it reduces localized concentration gradients and supports more stable neutralization behavior throughout the liquid volume. The lower portion of the chamber is shaped to support residue collection, while the main liquid zone remains available for treatment and neutralization.

The overall design is modular and adaptable. Tank dimensions, reagent limits, and control thresholds may be adjusted according to the wastewater load, treatment capacity, and practical operating needs of the SME unit. This flexibility is one of the main strengths of the proposed system, as it allows the design to be interpreted as a scalable concept rather than a fixed single-capacity arrangement.

A. DESIGN RATIONALE

The three-tank configuration was selected to preserve process clarity while maintaining compactness and operational simplicity. Separating wastewater collection, treatment, and reagent storage improves handling safety and reduces process confusion during operation. This arrangement also allows easier control of dosing quantity and treatment volume, which is particularly important in SME environments where manual intervention must be minimized.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

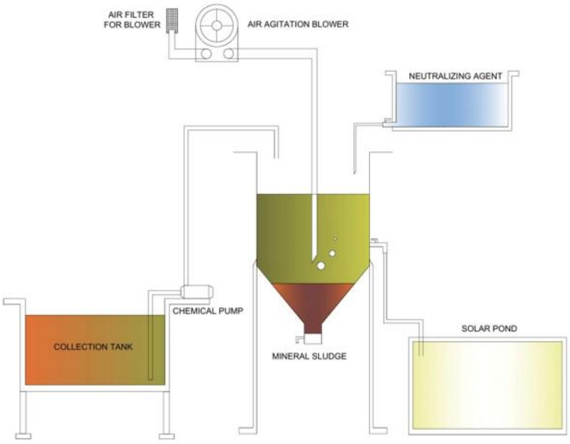

Fig. 1. Process schematic of the proposed compact waste neutralization system.

IV. CONTROL ARCHITECTURE

The control architecture is based on a closed-loop operating sequence involving sensing, decision-making, actuation, and reset. Wastewater is transferred to the treatment chamber, and the filling stage is terminated once the desired level is reached. The pH sensor then measures the process condition and provides the signal required for control action.

When the measured pH remains outside the acceptable band, the controller activates the dosing pump and initiates agitation. The dosing and mixing stages continue until the pH approaches the desired operating interval. In this way, the system reduces the dependence on manual judgment during chemical addition and improves the reliability of the neutralization sequence.

The essential control sequence may be summarized as follows: collection, transfer, level check, pH measurement, controlled dosing, agitation-assisted mixing, stabilization, discharge, and reset for the next cycle. This sequence is intentionally kept simple so that the system remains understandable and suitable for SME operation.

From a design perspective, the control logic is significant because it transforms the proposed setup from a passive tank arrangement into an active treatment system. The integration of sensor input with controlled actuation improves process repeatability while preserving operational simplicity, which is particularly important in smaller industrial environments.

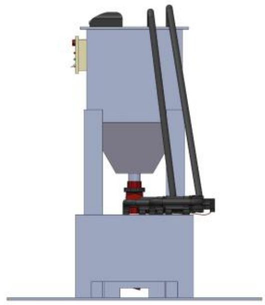

Fig. 2. Side CAD view of the proposed compact waste neutralization system.

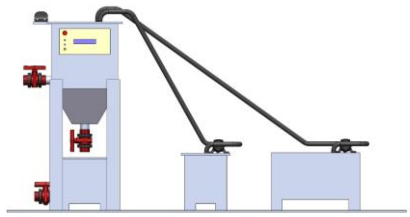

Fig. 3. Front CAD view of the proposed compact waste neutralization system.

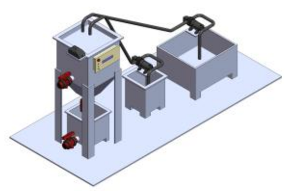

Fig. 4. Isometric CAD view of the proposed compact waste neutralization system.

V. DISCUSSION

The proposed design is intended as a practical neutralization solution rather than a full-scale advanced treatment plant. Its main value lies in combining basic mechanical layout with controlled sensing and dosing to achieve more dependable pH correction in small-volume wastewater streams. This makes the concept especially relevant for electroplating SMEs that require manageable treatment systems rather than complex multistage infrastructure.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

A. SYSTEM ADVANTAGES FOR SMEs

The practical value of the proposed system for SMEs lies in its compact footprint, simplified operation, and modular structure. Since many smaller electroplating units operate under space and cost constraints, a treatment concept that minimizes installation complexity can improve the likelihood of adoption. The use of sensing and controlled dosing reduces dependence on operator estimation, while the separate tank arrangement improves process clarity and safer reagent handling.

B. SCOPE AND LIMITATIONS

The present work is limited to conceptual system design and control-oriented process framing. It does not yet present extended experimental datasets, long-duration performance evaluation, or economic optimization. The study is intended to establish a practical engineering basis for future implementation and validation under real electroplating wastewater conditions.

From an SME perspective, the design is relevant because it addresses the core operational needs of compactness, ease of understanding, reduced manual intervention, and safer chemical handling. The inclusion of pH monitoring and agitation-assisted mixing is expected to improve dosing uniformity and treatment repeatability when compared with purely manual neutralization practices.

In addition, the design provides a useful base for future enhancement. Depending on industrial need, the system may later be extended with data logging, improved safety interlocks, downstream polishing modules, or more advanced residue-handling arrangements. This further supports its value as a foundational design concept for future development.

VI. CONCLUSION

This paper presented the design of a compact smart waste neutralization system for small and medium electroplating enterprises. The study addressed the limitations of large effluent treatment installations by proposing an SME-oriented alternative based on a compact tank arrangement, pH sensing, level monitoring, automated dosing, and agitation-assisted mixing.

The literature review indicated that although advanced treatment methods provide strong pollutant-removal capability, they often demand greater cost, infrastructure, and maintenance effort. In contrast, the proposed design focuses on practical neutralization through a simpler control-oriented architecture suited to decentralized industrial use.

Overall, the work establishes a concise and application-relevant design framework for a compact wastewater neutralization system capable of supporting safer, more consistent, and more practical pH correction in SME settings.

Future work may include detailed validation, control refinement, and performance evaluation under varied wastewater conditions.

REFERENCES

[1] S. Guo, H. Wang, X. Liu, and Z. Zhang, “Approaches for the treatment and resource utilization of electroplating sludge,” 2024.
[2] Y. Liu, J. Zhang, and L. Chen, “Bipolar membrane electrodialysis for acid–base recovery from industrial effluents,” 2023.
[3] P. Sharma and R. Singh, “Electrocoagulation-based treatment of metal finishing wastewater,” 2022.
[4] A. Das and K. Roy, “Hybrid membrane–EC systems for efficient pH control and heavy metal removal,” 2023.
[5] W. Chen and T. Zhao, “Smart sensor integration in automated pH neutralization systems,” 2022.
[6] H. Patel and V. Joshi, “PLC-based pH control for industrial effluent treatment,” 2021.
[7] Central Pollution Control Board (CPCB), India, “Effluent discharge standards for industrial units,” 2020.
[8] D. Raj and A. Kumar, “Low-cost compact wastewater treatment units for small industries,” 2023.