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From Waste to Value: Recovery, Optimization, and Reuse of Magnesium Hydroxide from Zero Liquid Discharge Wastewater for Sustainable Industrial Applications

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Abstract- — Zero Liquid Discharge (ZLD) systems are increasingly adopted to minimise industrial wastewater discharge; however, they generate concentrated brine streams rich in dissolved minerals. This study focuses on the recovery of magnesium hydroxide from ZLD wastewater using a controlled precipitation method and optimisation of key process parameters. The influence of pH (9–12), temperature (25–60°C), and reaction time (30–120 min) on recovery efficiency was systematically evaluated. Maximum recovery efficiency of approximately 91% was achieved at pH 11, 45°C, and 90 minutes reaction time. The recovered magnesium hydroxide exhibited satisfactory purity and demonstrated effective performance in neutralisation and contaminant removal tests. These findings are consistent with earlier studies on magnesium recovery from brine systems (Almousa et al., 2024; Yong et al., 2024).

Keywords— Zero Liquid Discharge (ZLD), industrial wastewater, brine streams, magnesium hydroxide recovery, controlled precipitation, pH optimization, temperature effect, reaction time, recovery efficiency, dissolved minerals, wastewater treatment, contaminant removal, chemical precipitation, process optimization, water reuse, environmental sustainability.

I. INTRODUCTION

With rapid industrial growth, wastewater management has become a critical environmental concern. Zero Liquid Discharge (ZLD) systems are widely adopted to eliminate liquid effluents by recovering water and concentrating dissolved solids (Panagopoulos, 2021; Tong & Elimelech, 2016). However, these systems generate concentrated brine streams that are often treated as waste despite containing valuable minerals (Ahmed et al., 2019; Kumar et al., 2022).

Among these minerals, magnesium is of significant importance and can be recovered in the form of magnesium hydroxide, which is widely used in wastewater treatment and environmental applications (Patel et al., 2021; Zhao et al., 2017). Conventional production methods are resource-intensive, making recovery from wastewater a sustainable alternative (Li et al., 2020; Singh et al., 2020).

Previous studies have demonstrated the feasibility of magnesium recovery using precipitation and other techniques (Gao et al., 2019; La Corte et al., 2022). This study aims to recover magnesium hydroxide from real ZLD wastewater, optimise the process parameters, and evaluate its potential for reuse.

II. MATERIALS AND METHODS

2.1 Sample Collection

Wastewater samples were collected from a ZLD system of an industrial facility. The sample consisted of concentrated brine obtained after evaporation processes (Qiu et al., 2019).

2.2 Recovery of Magnesium Hydroxide

Magnesium hydroxide was recovered through chemical precipitation by adding NaOH (1M) under continuous stirring at 300 rpm. The pH was adjusted between 9 and 12, resulting in precipitation of magnesium hydroxide (Chen et al., 2018; Gao et al., 2019). The precipitate was filtered, washed, and dried at 60°C.

2.3 Optimisation of Process Parameters

The following parameters were optimised:

- pH: 9–12
- Temperature: 25–60°C
- Reaction time: 30–120 minutes

Experiments were conducted in triplicate for accuracy (Reddy et al., 2018).

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2.4 Characterisation
The recovered material was analysed for:
- Purity
- Particle characteristics
- Physical appearance

2.5 Application Testing
The material was tested for:
- Neutralisation of acidic solutions
- Removal of contaminants from wastewater (Park et al., 2018; Zhao et al., 2017)

III. RESULTS

3.1 Recovery Efficiency
Recovery efficiency increased with pH, reaching a maximum of 91% at pH 11, consistent with earlier findings (La Corte et al., 2022).

3.2 Effect of Process Parameters

Parameter	Condition	Recovery Efficiency (%)
pH	9	62
	10	78
	11	91
	12	92
Temperature	25°C	70
	35°C	82
	45°C	91
	60°C	89
Reaction Time	30 min	68
	60 min	80
	90 min	91
	120 min	91

3.3 Properties of Recovered Material
The recovered magnesium hydroxide showed:

- Purity of 85–90%
- Fine particle formation
- Stability under normal conditions (Zhang et al., 2024)

3.4 Application Performance
The recovered material:
- Neutralised acidic solutions effectively (pH 4 to ~7.5)
- Reduced contaminants by 65–75%

These results align with previous studies (Zhang et al., 2024; Park et al., 2018).

IV. RESEARCH GAPS AND FUTURE OPPORTUNITIES

Despite advancements, several gaps remain:

- Limited studies on real industrial ZLD wastewater (Usman et al., 2025)
- Lack of large-scale implementation
- Variability in wastewater composition
- Limited economic and environmental analysis (Dutta et al., 2021)

Future work should focus on:
- Industrial-scale implementation
- AI-based optimisation
- Multi-resource recovery systems
- Life cycle and cost analysis (Chang et al., 2025)

V. DISCUSSION

The results confirm that pH significantly influences magnesium precipitation, with optimal recovery at pH 11 (Gao et al., 2019). Temperature affects reaction kinetics, with moderate conditions improving efficiency. Beyond 90 minutes, no significant improvement was observed, indicating equilibrium (Reddy et al., 2018).

Compared to conventional methods, this approach is cost-effective and environmentally sustainable (Li et al., 2020). However, variations in wastewater composition may affect consistency, requiring further standardisation (Wang et al., 2017).

VI. CONCLUSION

This study demonstrates that magnesium hydroxide can be effectively recovered from ZLD wastewater with recovery efficiency exceeding 90%. The recovered material shows good potential for reuse in wastewater treatment applications. This approach supports sustainable waste management and circular economy practices (Singh et al., 2020).

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