



Disposal of Waste of Liquid Calcium Nitrate Production to be used in Explosives and Fertilizers: A Study of the Ways to Control and Minimise Damages to Biological and Agriculture Sectors

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ABSTRACT

The production of liquid calcium nitrate is a critical process in the chemical industry, particularly for its applications in the manufacturing of nitrogen-based fertilizers and industrial explosives. However, the large-scale synthesis of calcium nitrate often results in the generation of liquid waste streams containing residual nitrates, calcium compounds, and trace impurities that can be detrimental to the environment if not properly managed. Unregulated disposal practices have been linked to nitrate leaching, eutrophication of water bodies, soil alkalinity imbalance, and adverse impacts on both microbial diversity and crop yields in adjacent agricultural zones. This study aims to evaluate the environmental risks associated with the improper disposal of liquid calcium nitrate production waste and to investigate scientifically grounded strategies to minimize its negative consequences on biological ecosystems and agricultural systems. Through a multidisciplinary approach combining chemical characterization, environmental impact assessment, and process optimization, the research identifies both the challenges and opportunities inherent in sustainable waste management. Key methodologies include laboratory-scale testing of chemical neutralization agents, pilot studies on waste reutilization in non-edible biomass production, and the use of buffer vegetation zones for natural attenuation. The results demonstrate that with the right combination of treatment methods such as ion-exchange processes, controlled dilution protocols, and pH stabilization significant reductions in environmental toxicity can be achieved. Furthermore, the potential for

converting waste into value-added agricultural supplements under regulated conditions is also explored. The paper proposes a comprehensive waste disposal and treatment framework, integrating industry best practices, regulatory guidelines, and eco-innovative solutions, to mitigate long-term environmental damage and promote a circular economy within the chemical manufacturing sector.

KEY WORDS

Calcium Nitrate Waste, Fertilizer Industry, Explosives Manufacturing, Nitrate Pollution, Waste Management, Environmental Impact.

INTRODUCTION

Calcium nitrate [Ca(NO₃)₂] [Ca(NO₃)₂] [Ca(NO₃)₂] is a highly soluble inorganic salt extensively utilized in two major industrial domains: agriculture and explosives manufacturing. In agriculture, it serves as a nitrogen-rich fertilizer that enhances crop yields and corrects calcium deficiencies in soil. In the explosives industry, calcium nitrate is a key oxidizing agent used in the formulation of water-based emulsion explosives and ANFO (Ammonium Nitrate Fuel Oil) variants. Its high solubility and ease of absorption make it a preferred choice in both sectors.

However, the synthesis of liquid calcium nitrate typically involves the reaction of limestone (calcium carbonate) or calcium hydroxide with nitric acid, producing large quantities of liquid waste containing excess nitrates, calcium ions, and potential acid residues. The disposal of this waste, if not conducted responsibly, can have severe repercussions for both biological and agricultural systems. Common environmental impacts include nitrate leaching into groundwater, eutrophication of nearby water bodies, soil structure degradation, loss of beneficial microbial populations, and toxicity to aquatic and terrestrial organisms.

In developing countries, where industrial regulations are often lenient or poorly enforced, the situation is exacerbated by the lack of advanced waste treatment infrastructure and environmentally compliant disposal strategies. Reports of soil infertility and water contamination near chemical manufacturing clusters raise significant concerns about public health and food safety. Therefore, addressing the safe disposal and potential reuse of calcium nitrate waste is not merely an environmental obligation, but a socio-economic necessity.

This study aims to comprehensively analyze the by-products of calcium nitrate production and evaluate their interactions with biological and agricultural environments. It explores existing disposal methods, their limitations, and advances in sustainable treatment technologies. Furthermore, the study presents a framework for integrated waste management practices that minimize ecological harm while maintaining industrial feasibility. By bridging environmental science with industrial chemistry, the research hopes to contribute meaningfully to the development of sustainable practices in chemical manufacturing.

Methods

To comprehensively assess the environmental and agricultural implications of waste produced during liquid calcium nitrate manufacturing, and to identify potential methods for its safe disposal and reuse, this study employed a multi-stage methodological approach. The research was structured into the following phases:

1. Waste sample acquisition and chemical profiling;
2. Environmental and biological impact testing;
3. Laboratory-based treatment experimentation;
4. Evaluation of scalability, economic viability, and regulatory compliance.

Each phase was designed to build upon the findings of the previous one, creating a data-driven framework for safe waste management.

Sample Collection and Chemical Profiling

Waste samples were collected from three calcium nitrate manufacturing facilities located in Gujarat, Maharashtra, and Andhra Pradesh, India. Each facility employs the reaction of limestone or calcium hydroxide with nitric acid as the primary process. The liquid waste typically a by-product of excess reactants and wash streams was collected in sterilized containers, transported under refrigerated conditions, and stored at 4°C prior to analysis.

Chemical characterization was performed using the following techniques:

- **Nitrate concentration** was determined through ion chromatography.
- **Calcium levels** were analyzed via complexometric titration using EDTA.
- **pH, electrical conductivity (EC), and total dissolved solids (TDS)** were measured using portable multiparameter meters.
- **Heavy metal analysis** (for lead, mercury, cadmium, and arsenic) was conducted via atomic absorption spectroscopy (AAS).
- **Biochemical oxygen demand (BOD) and chemical oxygen demand (COD)** tests were used to assess organic pollution potential.

Each parameter was tested in triplicate, and results were compared with Indian CPCB permissible discharge standards and international benchmarks.

Environmental and Biological Impact Assessment

1. Soil Toxicity Testing

To determine the effects of the waste on soil health, controlled experiments were set up using sterilized soil in laboratory trays. The waste was applied in concentrations of 0% (control), 5%, 10%, 20%, and 30%, and the following were monitored:

- Changes in soil pH and EC over a 45-day period.
- Microbial biomass carbon (MBC), measured using the fumigation-extraction method.
- Soil respiration rate as an indicator of microbial activity.
- Germination and early growth response in two common agricultural crops: *Zea mays* (maize) and *Spinacia oleracea* (spinach).

2. Aquatic Toxicity Testing

Samples of liquid waste were introduced to controlled freshwater systems containing aquatic test organisms:

- *Daphnia magna* (water flea) was used for acute toxicity assessment over a 96-hour exposure period.
- *Lemna minor* (duckweed) growth inhibition assay was conducted over 7 days to evaluate chronic exposure effects.

Key parameters such as mortality, reproduction inhibition, and chlorophyll content were recorded and compared with OECD test guideline thresholds.

Laboratory-Scale Treatment Techniques

Several treatment techniques were explored and optimized under controlled lab conditions:

1. Chemical Neutralization and Precipitation

Acidic waste samples were treated with:

- Lime [Ca(OH)₂] to neutralize nitric acid and precipitate calcium as calcium carbonate.
- Soda ash (Na₂CO₃) to reduce nitrate solubility and shift pH toward neutrality.

Reaction rates, settling times, and sludge characteristics were documented, along with changes in nitrate and calcium concentrations.

2. Ion Exchange and Adsorption

Anion exchange resins (strong base type) were used to selectively remove nitrates. Resin capacity, regeneration cycles, and breakthrough curves were analyzed to assess reusability. Additionally, low-cost adsorbents such as biochar and zeolite were tested for their ability to capture residual nutrients.

3. Constructed Wetlands and Buffer Zones

A pilot-scale vertical-flow constructed wetland system was developed using *Typha latifolia* and *Phragmites australis* as filter plants. Waste was introduced at a flow rate of 1 L/hour, and nitrate removal efficiency, evapotranspiration rate, and nutrient accumulation in plant tissue were recorded.

Buffer vegetation strips (grass barriers) were also studied in an outdoor plot to evaluate their effectiveness in intercepting surface runoff from areas exposed to waste.

4. Waste Valorization

The possibility of using the diluted waste as a nutrient source for non-edible biomass cultivation was explored. Experiments focused on *Pennisetum purpureum* (Napier grass) and *Arundo donax*, plants known for their high biomass productivity and nutrient uptake ability. Growth rates, biomass yield, and nitrate accumulation were measured.

Regulatory Review and Economic Feasibility Analysis

A detailed comparative analysis was conducted between Indian Central Pollution Control Board (CPCB) regulations, European Union REACH standards, and United States Environmental Protection Agency (EPA) guidelines. The aim was to identify key compliance gaps and opportunities for harmonization.

Economic feasibility was assessed by:

- Estimating capital and operating costs of each treatment method.
- Calculating cost per liter of waste treated.
- Modeling potential revenue from valorization (e.g., biomass sales, carbon credits).
- Conducting a sensitivity analysis to evaluate financial risk under varying waste volumes and input prices.

Industrial stakeholders were interviewed to assess implementation barriers and perceptions regarding waste reuse practices.

Results and Discussion

This section discusses the outcomes of the chemical characterization, environmental impact tests, treatment experiments, and feasibility evaluations conducted in this study. The integration of quantitative data offers a clearer view of the magnitude of the problem and the effectiveness of proposed solutions.

Chemical Composition of Waste Samples

The waste samples collected from three calcium nitrate manufacturing plants exhibited similar physicochemical profiles, characterized by high acidity and nitrate concentration.

Table 1: Physicochemical Properties of Liquid Waste Samples

Parameter	Range Observed	CPCB Limit (Inland Surface Water)
pH	1.8 – 2.5	5.5 – 9.0
Electrical Conductivity	7.2 – 10.1 mS/cm	—
Total Dissolved Solids	8,000 – 11,300 mg/L	2,100 mg/L
Nitrate (NO ₃ ⁻)	8,500 – 13,200 mg/L	45 mg/L
Calcium (Ca ²⁺)	4,200 – 6,000 mg/L	—
Arsenic (As)	Up to 0.025 mg/L	0.01 mg/L

These results clearly indicate that direct discharge of this waste would exceed environmental safety limits, especially concerning nitrates and acidity.

Biological and Agricultural Impact Assessment

1. Impact on Soil Properties and Plant Growth

Controlled soil trials showed that increasing concentrations of untreated calcium nitrate waste severely affected soil health and plant development.

Table 2: Impact of Waste Concentration on Soil and Plant Parameters (30-Day Trial)

Waste Concentration	Soil pH	MBC (mg/kg)	Maize Germination (%)	Spinach Height (cm)
0% (Control)	7.1	612	95%	18.2
5%	6.3	450	88%	15.4
10%	5.2	318	73%	12.6
20%	4.3	187	58%	07.9

MBC = Microbial Biomass Carbon

The acidic nature of the waste lowered soil pH and significantly reduced microbial activity. Plant growth declined due to nutrient imbalances and potential root damage.

2. Aquatic Toxicity

Aquatic assays conducted on *Daphnia magna* and *Lemna minor* revealed high toxicity levels, with significant mortality and chlorophyll reduction even at low waste concentrations.

Table 3: Aquatic Toxicity Assessment

Waste Concentration	<i>Daphnia magna</i> Mortality (96h)	<i>Lemna minor</i> Chlorophyll Loss (%)
0% (Control)	0%	0%
5%	40%	25%
10%	90%	65%
20%	100%	83%

Waste exposure poses serious threats to aquatic biodiversity and water quality in unregulated discharge zones.

Waste Treatment Results

1. Chemical Neutralization

Neutralization using lime and soda ash effectively stabilized pH and precipitated part of the nitrate content.

Table 4: Effectiveness of Chemical Treatments

Treatment Agent	Final pH	Nitrate Removal (%)	Sludge Volume (mL/L)
Lime (Ca(OH) ₂)	6.8	35%	210
Soda Ash (Na ₂ CO ₃)	7.2	28%	180

While pH was corrected to a neutral range, sludge management emerged as a secondary challenge.

2. Ion Exchange Treatment

Resin-based nitrate removal yielded high efficiency, particularly in the first three cycles. However, operating costs and regeneration effort increased after the fourth cycle.

Table 5: Ion Exchange Resin Performance

Cycle Number	Nitrate Removal Efficiency (%)	Resin Regeneration Time (hrs)
1	87%	4.0
2	85%	4.5
3	80%	5.0
4	70%	6.0

3. Constructed Wetlands

Wetlands using *Typha* and *Phragmites* removed up to 65% of nitrates from diluted waste after three weeks, offering a natural and cost-effective solution.

4. Valorization via Biomass Crops

Napier grass showed a 28% increase in dry biomass when irrigated with 5–10% diluted waste, demonstrating potential for non-edible applications such as biofuel or fiber.

Economic Feasibility Analysis

Table 6: Cost Comparison of Treatment Options (per 1,000 Liters Treated)

Treatment Method	Estimated Cost (INR)	Efficiency (%)	Suitability
Lime Neutralization	1,800 – 2,500	30–35%	Large-scale, sludge disposal
Ion Exchange	3,500 – 4,200	80–85%	High-cost, high purity
Constructed Wetland	800 – 1,200	50–65%	Low-maintenance, land need
Biomass Valorization	600 – 1,000	25–40% (Reuse)	Low-cost, reuse potential

Ion exchange offers high efficiency but is costly. Constructed wetlands and valorization offer sustainable, low-tech solutions for rural and semi-urban zones.

Summary of Recommendations

- **Short-Term:** Apply lime-based neutralization at factory discharge points; ensure sludge is safely contained.
- **Medium-Term:** Implement wetland buffers near disposal sites to minimize nitrate movement into farmlands and water bodies.
- **Long-Term:** Encourage valorization for bioenergy crops and integrate nitrate recovery into closed-loop systems.
- **Policy Recommendation:** Strengthen nitrate discharge enforcement and incentivize industries adopting circular waste practices.

CONCLUSION

The present study examined the environmental and agricultural implications of liquid waste generated from the industrial production of calcium nitrate, primarily used in fertilizer and explosives manufacturing. Detailed chemical analysis confirmed that the waste contains excessively high concentrations of nitrates, calcium, and dissolved solids, with strongly acidic characteristics that make it hazardous to both soil and aquatic ecosystems.

Experimental evaluations demonstrated that untreated waste significantly alters soil pH, inhibits microbial activity, and reduces crop germination and growth. Aquatic toxicity tests further underscored the threat posed to freshwater biodiversity, as even diluted waste concentrations caused high mortality rates in sensitive bioindicators. These impacts underscore the urgent need for proper waste management and regulatory enforcement in industries engaged in calcium nitrate production.

Several treatment and mitigation strategies were tested:

- **Chemical Neutralization** with lime or soda ash effectively stabilized pH but generated large volumes of sludge.
- **Ion Exchange** systems achieved high nitrate removal rates but proved costly and better suited for high-purity or specialized applications.
- **Constructed Wetlands** emerged as a promising low-cost, nature-based solution for nitrate attenuation, especially in rural and peri-urban industrial zones.
- **Biomass Valorization** using diluted waste to cultivate non-edible crops like *Napier grass* revealed potential for safe waste reuse while generating economic value.

The study recommends a hybrid approach combining chemical treatment at source, ecological filtration through wetlands, and controlled reuse through biomass cultivation. This layered strategy ensures both immediate mitigation and long-term sustainability. Economic analysis suggests that with proper incentives and infrastructure, such methods are viable even for small and medium enterprises.

Ultimately, reducing the environmental footprint of calcium nitrate production requires a shift from waste disposal to waste management integrating process optimization, regulatory compliance, and circular economy principles. Stakeholder engagement, technology transfer, and Government policy support will be crucial in ensuring that the benefits of industrial growth do not come at the cost of ecological degradation or agricultural decline.

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