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Comparative Study on the Effectiveness of Poly Aluminium Chloride (PAC), Aluminium Sulfate, and Iron Sulfate in Livestock Wastewater Treatment

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Author's contribution

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study investigates the effectiveness of chemical coagulation methods for treating livestock wastewater, a significant environmental concern due to the high levels of organic and inorganic pollutants it contains. The coagulants employed in this research include Poly Aluminium Chloride

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(PAC), Aluminum Sulfate ($Al_2(SO_4)_3 \cdot 18H_2O$), and Iron Sulfate ($FeSO_4 \cdot 7H_2O$). Experimental results demonstrate that the treatment with PAC achieved the highest reduction in Chemical Oxygen Demand (COD), with values decreasing from an initial concentration of 1431.32 mg/L to 700.18 mg/L, corresponding to a removal efficiency of 77.38%. Similarly, Biochemical Oxygen Demand (BOD_5) values decreased from 1734.43 mg/L to 417.33 mg/L, achieving a removal efficiency of 75.68%. The Total Suspended Solids (TSS) also showed a significant reduction, reaching 112.02 mg/L after treatment, well below the regulatory limit of 150 mg/L as stipulated by QCVN 62-MT:2016/BTNMT. While Aluminum Sulfate and Iron Sulfate demonstrated some level of effectiveness, their results did not meet the regulatory standards, with residual COD, BOD_5, and TSS concentrations remaining above permissible limits. This study concludes that PAC is the most effective coagulant for livestock wastewater treatment, suggesting further optimization and potential application in agricultural settings to mitigate the environmental impact of livestock operations.

Keywords: Livestock wastewater; chemical coagulation; Poly Aluminium Chloride (PAC); water quality treatment; sustainable agriculture.

ABBREVIATION

QCVN : Vietnamese National Technical Regulation
TSS Total : Suspended Solids
COD : Chemical Oxygen Demand
BOD5 : Biochemical Oxygen Demand (5-day)
PAC : Poly Aluminium Chloride
MT : Environment
BTNMT : Ministry of Natural Resources and Environment
TN : Total Nitrogen

1. INTRODUCTION

The livestock industry is a vital component of the global economy, contributing significantly to food security and rural livelihoods. However, the rapid expansion of livestock production has resulted in substantial wastewater generation, characterized by high concentrations of organic matter, nutrients, and pathogens. This wastewater poses serious risks to water quality and public health, necessitating effective treatment solutions to prevent environmental degradation.

Livestock wastewater typically contains a variety of pollutants, including nitrogen compounds, suspended solids, and pathogenic microorganisms. Among these pollutants, high levels of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD_5) indicate the presence of organic matter, while Total Suspended Solids (TSS) can contribute to turbidity and reduce light penetration in aquatic environments. Effective treatment of livestock wastewater is critical not only for environmental protection but also for compliance with regulatory standards, such as those outlined in QCVN 62-MT:2016/BTNMT.

Chemical coagulation is recognized as a powerful method for wastewater treatment, utilizing coagulants to aggregate suspended particles and enhance their removal through sedimentation. This process relies on the electrostatic attraction between charged particles and coagulant molecules, which facilitates the formation of larger aggregates or flocs. In this study, we aim to evaluate the performance of three coagulants—Poly Aluminium Chloride (PAC), Aluminum Sulfate, and Iron Sulfate—on the treatment efficiency of livestock wastewater. By analyzing the reductions in COD, BOD_5, and TSS, we seek to identify the most effective coagulant and its optimal dosage to improve water quality and support sustainable livestock farming practices.

2. MATERIALS AND METHODS

2.1 Research Materials

PAC: Poly Aluminium Chloride
Aluminum Sulfate: $Al_2(SO_4)_3 \cdot 18H_2O$
Iron Sulfate: $FeSO_4 \cdot 7H_2O$

2.2 Wastewater Sampling Method

Livestock wastewater samples were collected in accordance with the regulations outlined in

QCVN 62-MT:2016/BTNMT: The wastewater sampling process for laboratory experiments includes the following steps: Prepare sample containers (1-2 liters), gloves, and personal protective equipment. Samples are taken at representative locations, typically at the outlet of the wastewater treatment system, at various times throughout the day. During sampling, submerge the container 20-30 cm below the water surface, fill 80-90% of its volume, and label it with the necessary information (sample code, time, location). Samples should be stored at 4°C and transported to the laboratory within 24 hours. Environmental conditions and wastewater characteristics must be carefully documented.

2.3 Wastewater Sample Preservation Method

Livestock wastewater samples were preserved according to the regulations specified in TCVN 6663-3:2016

2.4 Experimental Method

In this experiment, three chemicals were used for coagulation: PAC, Aluminum Sulfate, and Iron Sulfate. The chemicals were applied at the same concentrations for 1 liter of water:

- T1: 0.25g of chemical
- T2: 0.5g of chemical
- T3: 0.75g of chemical
- T4: 1.0g of chemical
- T5: 1.25g of chemical

Stir the mixture evenly using a glass rod. Allow the solution to settle until complete phase separation is observed. Use a pipette to extract the clear solution and analyze it for COD (Chemical Oxygen Demand) to determine the optimal concentration for each of the three chemicals. Once the optimal concentration for each chemical is identified, further analysis will be conducted on various water quality parameters to evaluate the effectiveness of the coagulants at different concentrations.

2.5 Analytical Method

COD (Chemical Oxygen Demand): Analyzed using the potassium dichromate method.

BOD_5 (Biochemical Oxygen Demand): Determined by incubating samples in a controlled environment at 20°C for 5 days, followed by measuring dissolved oxygen (DO) with a DO meter.

TSS (Total Suspended Solids): Measured using the filtration and drying method to determine mass.

Total Nitrogen: Determined using the Kjeldahl method.

The analysis results were compared with QCVN 62:2016/BTNMT: National Technical Regulation on Livestock Wastewater.

2.6 Data Processing Method

The data were processed using the statistical software IRISSTAT 5.0.

3. RESULTS AND DISCUSSION

Livestock wastewater contains a significant amount of organic and inorganic particulate matter (Bazrafshan et al. 2012) with small sizes, making it difficult to settle and separate through mechanical methods, which can be time-consuming (Sievers et al. 1994). The organic matter includes proteins from animal waste, carbohydrates from undigested feed, lipids and fats from excreta, volatile fatty acids (VFAs) produced during microbial decomposition, urea and ammonia from urine, and organic acids generated by the fermentation of organic materials (Jensen et al. 2013). On the other hand, the inorganic matter consists of minerals such as calcium, phosphorus, and potassium, heavy metals like copper, zinc, and cadmium from feed additives and veterinary treatments, as well as inorganic salts and suspended solids from soil, dust, and cleaning agents (Varel 2002).

The use of coagulant chemicals in livestock wastewater treatment, such as PAC, Aluminum Sulfate, and Iron Sulfate (Bahrodin et al. 2021) can effectively remove these substances (Kang et al. 2022) When coagulants are added to the wastewater, the positively charged particles will attract the negatively charged suspended particles present in the water (Padmaja et al. 2020). Once the electric potential of the water is disrupted, these oppositely charged particles will aggregate into larger flocs (Precious Sibiya et al. 2021) facilitating faster sedimentation and clarification (Akhtar et al. 2024).

The coagulation mechanisms of each coagulant are as follows:

3.1 Poly Aluminium Chloride (PAC)

PAC operates through a polymerization process, creating highly charged aluminum ions. These positively charged ions neutralize the negatively charged particles in the wastewater. Once neutralized, the particles aggregate into larger flocs through precipitation. PAC has the advantage of forming larger, more stable flocs while producing less sludge compared to other coagulants, enhancing treatment efficiency and reducing operational costs (Park et al. 2000).

3.2 Aluminum Sulfate ($Al_2(SO_4)_3$)

Alum functions by releasing aluminum ions (Al^{3+}'into the water, which neutralize negatively charged suspended solids, allowing them to aggregate into flocs. Additionally, aluminum ions combine with water to form aluminum hydroxide ($Al(OH)_3$), a gelatinous precipitate that helps adsorb suspended particles. However, for optimal performance, alum requires a specific pH range (typically between 5.5 and 7.5) (Kang et al. 2022).

3.3 Ferric Sulfate ($Fe_2(SO_4)_3$)

Ferric sulfate, like alum, releases ferric ions (Fe^{3+}) into the wastewater. These ions neutralize negatively charged suspended particles and form larger flocs. Ferric ions also generate ferric hydroxide ($Fe(OH)_3$), a strong adsorbing agent. Ferric sulfate is particularly effective in slightly acidic conditions (pH range 4-6), making it suitable for wastewater with lower pH levels (Parmar et al. 2011, Lu et al. 2020).

The concentration or content of Chemical Oxygen Demand (COD) in livestock wastewater refers to the amount of oxygen required to chemically oxidize organic and inorganic matter present in the water (Hellal et al. 2000). COD is a critical parameter for assessing the quality of wastewater and its potential environmental impact (AbdollahzadehSharghi et al. 2018).

In livestock operations, waste generated from animals contains a variety of organic materials, including manure, feed residues, and other biodegradable substances (Wolf et al. 2015). When this waste is mixed with water, it creates wastewater that can have high levels of COD (Arturi et al. 2019).

The treatment of wastewater was conducted using PAC at varying amounts of 0.25g to 1.25g, resulting in a treatment efficiency increase from 53.76% to 76.32%, with the COD concentration after treatment decreasing from 1431.32 mg/L to 732.99 mg/L. Since the treatment efficiency continuously increased within the range of 0.25g to 1.25g, the optimal coagulant dosage has yet to be determined.

When the PAC dosage was increased to 1.5g (T6), the COD concentration after treatment rose to 768.283 mg/L, and the treatment efficiency decreased to 75.18%. This indicates that increasing the PAC dosage to 1.5g exceeded the optimal threshold for the coagulant, resulting in a surplus.

Following the increase in PAC dosage to 1.5g, the COD concentration after coagulation increased, and the treatment efficiency decreased compared to the 1.25g level. Sensory evaluation showed that increasing the PAC dosage to 1.5g resulted in slightly turbid water with more suspended solids. Therefore, using PAC at a concentration of 1.25g/L provides the highest efficiency for livestock wastewater treatment.

Table 1. Effect of PAC concentration on livestock wastewater treatment efficiency

Concentration (g/L)	COD before coagulation (mg/L)	COD after coagulation (mg/L)	Treatment efficiency (%)
T1	3095.42	1431.32	53.76
T2	3095.42	1348.67	56.43
T3	3095.42	1184.61	61.73
T4	3095.42	982.176	68.27
T5	3095.42	732.99	76.32
T6	3095.42	768.283	75.18

Table 2. Effect of aluminum sulfate concentration on livestock wastewater treatment efficiency

Concentration (g/L)	COD before coagulation (mg/L)	COD after coagulation (mg/L)	Treatment efficiency (%)
T1	3095.42	1513.96	51.09
T2	3095.42	1406.55	54.56
T3	3095.42	1055.22	65.91
T4	3095.42	786.85	74.58
T5	3095.42	862.07	72.15

From the analysis results, the optimal dosage of Aluminum Sulfate for treatment is 1g/L, achieving a treatment efficiency of 74.58% compared to the other dosage levels. When the concentration of Aluminum Sulfate was increased, the treatment efficiency decreased to 72.15%, indicating that the dosage of 1.25g exceeded the optimal threshold for the coagulant. This is attributed to the increased hydrolysis of aluminum salts (Al^{3+}) in water, which releases more H^+ ions, thereby reducing the pH of the water (Zamani et al. 2019). Therefore, using Aluminum Sulfate at a concentration of 1g/L provides the highest efficiency for livestock wastewater treatment.

The results indicate that the optimal dosage of Iron Sulfate for treatment is 0.75g/L. Observations showed that when the dosage was increased to 1g/L, the coagulation process was disrupted, leading to turbid water with higher color intensity. Therefore, using Iron Sulfate at a concentration of 0.75g/L provides the highest efficiency for livestock wastewater treatment.

Based on the results of the experiments conducted on livestock wastewater treated with coagulants such as PAC, Aluminum Sulfate, and Iron Sulfate, the optimal dosages were selected for coagulation experiments. Specifically, the optimal dosages are 1.25g/L for PAC, 1g/L for Aluminum Sulfate, and 0.75g/L for Iron Sulfate. All the coagulants used in the treatment demonstrated high efficiency and significantly reduced the concentration of pollutants compared to the initial levels before treatment. However, each coagulant exhibited different levels of treatment efficiency and was influenced by various factors.

The concentration or content of Total Suspended Solids (TSS) in livestock wastewater refers to the amount of solid particles that are suspended in the water (Nwabanne 2019). These solids can include organic materials such as manure, feed particles, and plant matter, as well as inorganic materials like soil and minerals (Farzadkia et al. 2016).

From the results table and comparison chart, it is evident that the TSS concentration after treatment with each type of coagulant significantly decreased compared to the values before treatment. The highest treatment efficiency was achieved using PAC, with a reduction of 95.67%, resulting in a TSS concentration of 112.02 mg/L, which is lower than the 150 mg/L limit specified in QCVN 62-MT:2016/BTNMT.

The use of Aluminum Sulfate also resulted in a TSS concentration after treatment of 137.36 mg/L, which is within the permissible limits of the regulation. However, when Iron Sulfate was used for treating livestock wastewater, the TSS removal efficiency was not satisfactory, yielding a post-treatment value of 547.92 mg/L, which exceeds the regulatory standard by 3.65 times.

It can be observed that when treating wastewater with high TSS and turbidity levels, such as livestock wastewater, the highest TSS removal efficiency is achieved with PAC, followed by Aluminum Sulfate, and the lowest efficiency is observed with Iron Sulfate.

Table 3. Effect of Iron Sulfate concentration on livestock wastewater treatment efficiency

Concentration (g/L)	COD before coagulation (mg/L)	COD after coagulation (mg/L)	Treatment efficiency (%)
T1	3095.42	1681.74	45.67
T2	3095.42	1354.24	56.25
T3	3095.42	1060.5	65.74
T4	3095.42	1138.8	63.21
T5	3095.42	1158.61	62.75

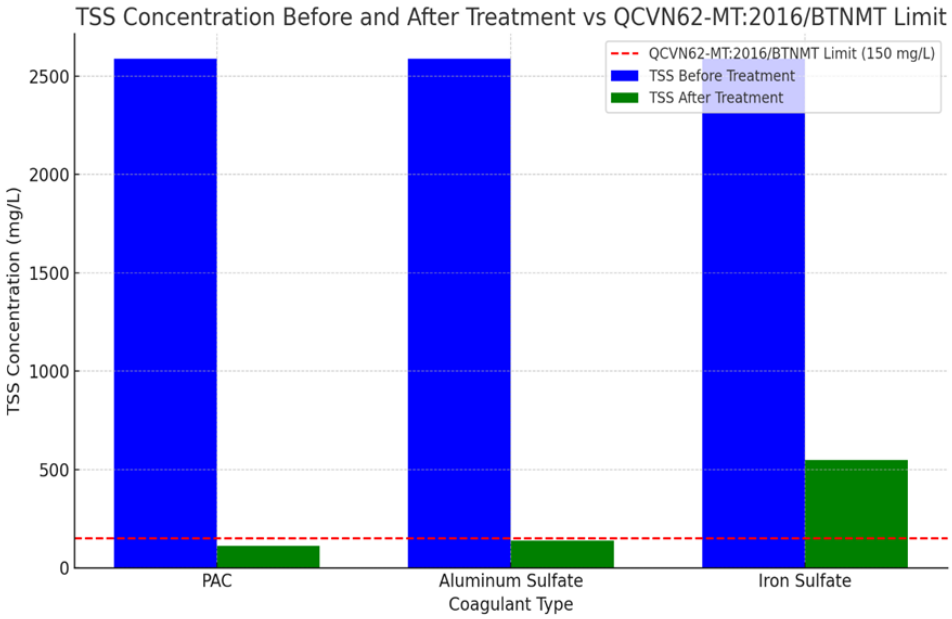

Fig. 1. The TSS concentration of livestock wastewater samples before and after chemical treatment was evaluated and compared with QCVN 62-MT:2016/BTNMT

Table 4. TSS concentration of livestock wastewater samples before and after chemical treatment

Parameters and Indicators	PAC	Aluminum Sulfate	Iron Sulfate	QCVN62-MT:2016/BTNMT
TSS before treatment (mg/L)	2587	2587	2587	150
TSS after treatment (mg/L)	112.01	137.36	547.92	
Treatment efficiency (%)	95.67%	94.69%	78.82%	-

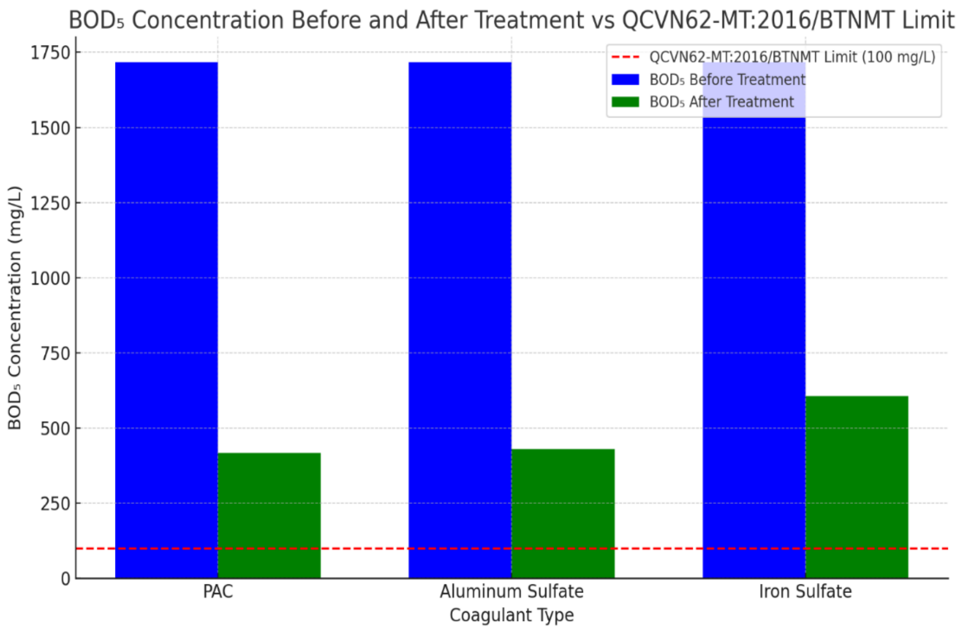

Fig. 2. The BOD_5 concentration of livestock wastewater samples before and after chemical treatment was evaluated and compared with QCVN 62-MT:2016/BTNMT

Table 5. BOD_5 concentration of livestock wastewater samples before and after chemical treatment

Parameters and Indicators	PAC	Aluminum Sulfate	Iron Sulfate	QCVN62-MT:2016/BTNMT
BOD_5 before treatment (mg/L)	1716.02	1716.02	1716.02	100
BOD_5 after treatment (mg/L)	417.33	429.51	605.41	
Treatment efficiency (%)	75.68	74.97	64.72	-

Table 6. COD_5 concentration of livestock wastewater samples before and after chemical treatment

Parameters and Indicators	PAC	Aluminum Sulfate	Iron Sulfate	QCVN62-MT:2016/BTNMT
COD_5 before treatment (mg/L)	3095.42	3095.42	3095.42	300
COD_5 after treatment (mg/L)	700.18	797.07	1070.39	
Treatment efficiency (%)	77.38%	74.25%	65.42%	-

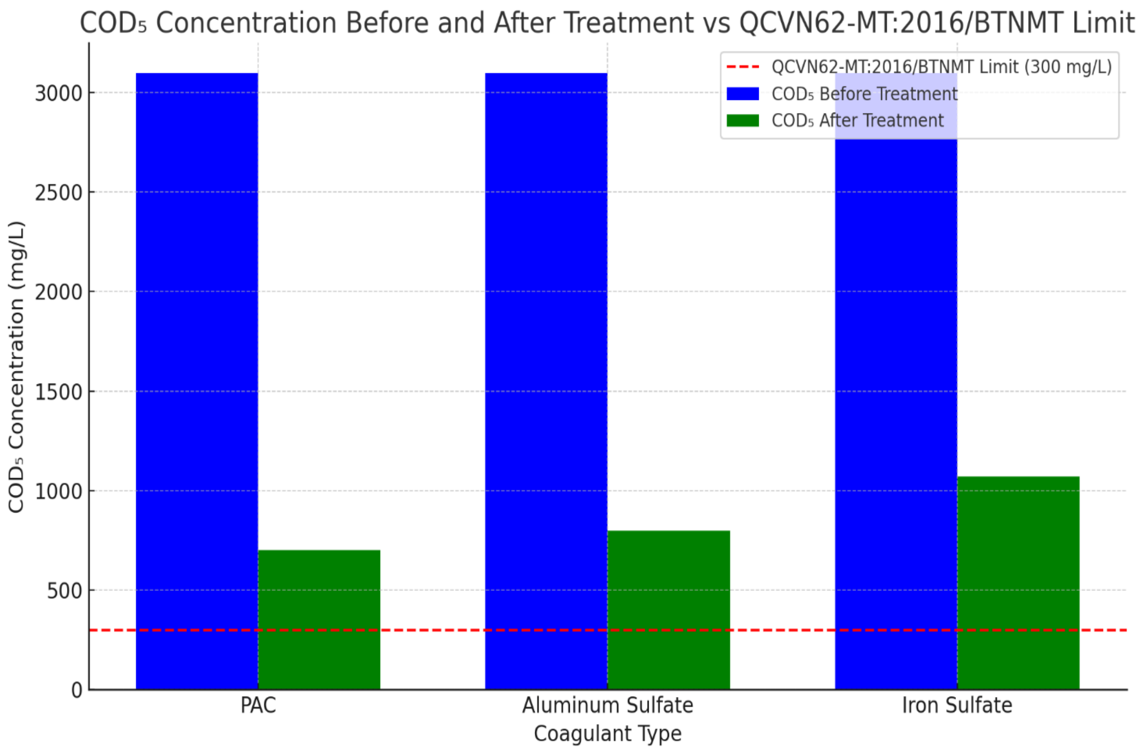

Fig. 3. The COD_5 concentration of livestock wastewater samples before and after chemical treatment was evaluated and compared with QCVN 62-MT:2016/BTNMT

The concentration or content of Biochemical Oxygen Demand over 5 days (BOD_5) in livestock wastewater refers to the amount of oxygen that microorganisms require to decompose organic matter in the water within a five-day period at a specified temperature, typically 20°C (Tak et al. 2015). BOD5 is a key indicator of the organic pollution level in wastewater (Omar 2019).

The results after the experiments show that the BOD_5 values following treatment with PAC, Aluminum Sulfate, and Iron Sulfate all demonstrated significant reductions compared to the initial BOD_5 levels; however, they still exceed the permissible limits set by QCVN 62-MT:2016/BTNMT. Specifically, after treatment with PAC, the BOD_5 value was reduced to 417.33 mg/L, achieving a treatment efficiency of 75.68%. After treatment with Aluminum Sulfate, the BOD_5 value decreased to 429.51 mg/L, with a treatment efficiency of 74.97%. Lastly, after treatment with Iron Sulfate, the BOD_5 value was reduced to 605.41 mg/L, resulting in a treatment efficiency of 64.72%.

In conclusion, the BOD_5 values for livestock wastewater after treatment with PAC, Aluminum Sulfate, and Iron Sulfate remain high and fall outside the permissible limits established by QCVN 62-MT:2016/BTNMT. The highest BOD_5 treatment efficiency was achieved using PAC, while the lowest was observed with Iron Sulfate.

The experimental results indicate that the COD values of the wastewater significantly decreased compared to the initial COD levels. Specifically, after treatment with PAC, the remaining COD value was 700.18 mg/L, resulting in a treatment efficiency of 77.38%. After treatment with Aluminum Sulfate, the remaining COD value was 797.07 mg/L, achieving a treatment efficiency of 74.25%. Finally, after treatment with Iron Sulfate, the COD value was 1070.39 mg/L, with a treatment efficiency of 65.42%.

Thus, coagulation treatment of livestock wastewater using PAC, Aluminum Sulfate, and Iron Sulfate resulted in the highest COD treatment efficiency with PAC, followed by Aluminum Sulfate, and the lowest efficiency was observed with Iron Sulfate. Although the COD values after treatment with all three coagulants showed a reduction compared to the initial concentrations, they still exceeded the permissible limits established by QCVN 62-MT:2016/BTNMT.

The concentration or content of Total Nitrogen (TN) in livestock wastewater refers to the sum of all forms of nitrogen present in the water (Teh et al. 2016). This includes organic nitrogen, ammonia nitrogen (NH_4^+), nitrite nitrogen (NO_2^-), and nitrate nitrogen (NO_3^-) (Mguni and Taurai 2015). Total Nitrogen is an important parameter in assessing the quality of wastewater, particularly in agricultural settings (Putri and Sutrasno 2018).

Table 7. Total Nitrogen concentration of livestock wastewater samples before and after chemical treatment

Parameters and Indicators	PAC	Aluminum Sulfate	Iron Sulfate	QCVN62-MT:2016/BTNMT
TN before treatment (mg/L)	487.31	487.31	487.31	50
TN after treatment (mg/L)	246.67	250.47	257.54	
Treatment efficiency (%)	49.38%	48.6%	47.15%	-

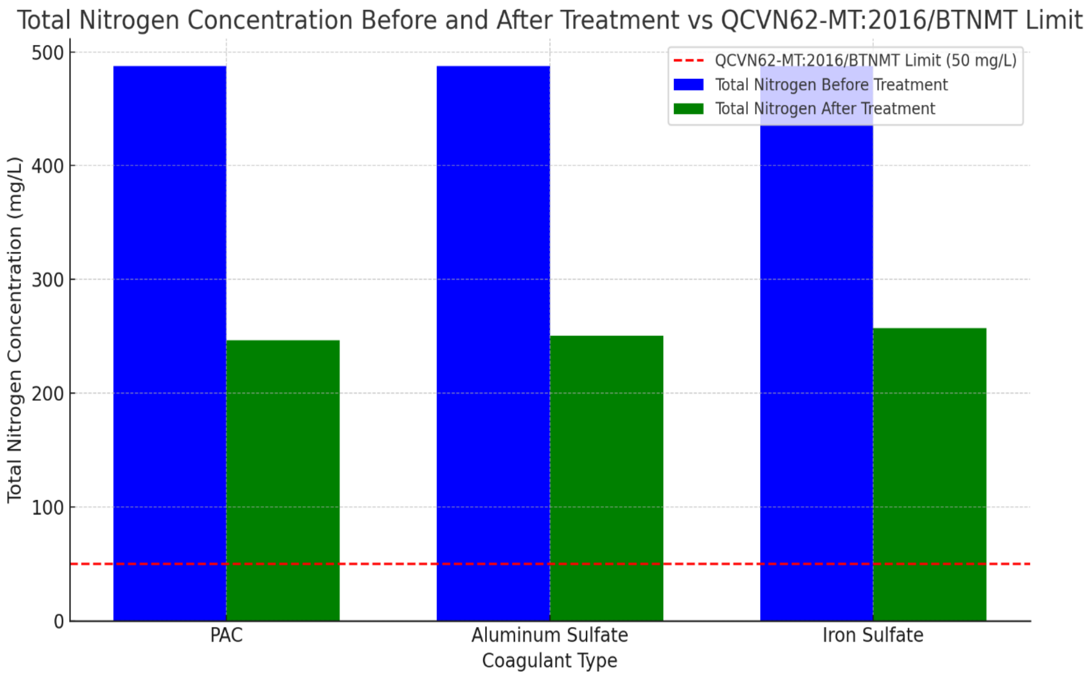

Fig. 4. The Total Nitrogel concentration of livestock wastewater samples before and after chemical treatment was evaluated and compared with QCVN 62-MT:2016/BTNMT

The results of using coagulants to treat Total Nitrogen levels in livestock wastewater show significant effectiveness, reducing the concentration compared to the initial levels. However, the treated levels still exceed the permissible limit of 50 mg/L set by the regulations. Specifically, the results are as follows:

Initial Total Nitrogen Concentration: 487.31 mg/L
After Treatment with PAC: 246.67 mg/L
After Treatment with Iron Sulfate: 257.54 mg/L
After Treatment with Aluminum Sulfate: 250.47 mg/L

Despite the notable reductions achieved with all three coagulants, the final concentrations remain significantly above the permissible limit, being more than 2.5 times higher than the standards established in QCVN 62-MT: 2016/BTNMT. This indicates the need for further optimization of the treatment process or the exploration of additional methods to achieve compliance with environmental regulations.

4. CONCLUSION

The results of this study clearly demonstrate that chemical coagulation is an effective method for reducing pollutant concentrations in livestock wastewater. Among the coagulants tested, Poly Aluminium Chloride (PAC) emerged as the most effective, achieving significant reductions in COD, BOD_5, and TSS. The treatment with PAC not only brought COD levels down to 700.18 mg/L, indicating a removal efficiency of 77.38%, but also reduced BOD_5 and TSS concentrations to levels that approached regulatory compliance.

Conversely, while Aluminum Sulfate and Iron Sulfate showed some effectiveness, the residual pollutant levels post-treatment were still above permissible limits set by QCVN 62-MT:2016/BTNMT. This finding highlights the importance of selecting the appropriate coagulant for specific wastewater characteristics. The study also indicates that exceeding the optimal dosage of coagulants can lead to decreased treatment efficiency, as observed with Iron Sulfate, where increasing concentrations resulted in lower performance due to potential oversaturation and subsequent floc destabilization.

In conclusion, this research underscores the critical role of PAC in the treatment of livestock wastewater, suggesting its implementation as a viable solution to mitigate the environmental impacts associated with livestock operations. Future studies should focus on optimizing coagulant dosages, exploring combinations of coagulants, and investigating additional treatment methods, such as biological treatment or advanced oxidation processes, to further enhance wastewater treatment efficiency and ensure compliance with environmental regulations. The findings of this study contribute to the growing body of knowledge on sustainable agricultural practices and environmental protection.

The major drawback of this method is the production of sludge, which is a byproduct of the treatment process. Managing and disposing of this sludge is a critical issue that must be considered, as it can pose environmental risks if not handled properly.

When recommending chemical treatment as an effective wastewater treatment method, it is essential to include strategies for the safe handling, treatment, and disposal of the resulting sludge. Failing to address this aspect can undermine the environmental benefits of the treatment process, shifting the pollution problem from liquid waste to solid waste.

Therefore, future research and practical applications should not only focus on the chemical treatment efficiency but also on sustainable sludge management solutions, such as sludge minimization, resource recovery, or safe disposal practices

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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