



Research article

Evaluation of an electrocoagulation–bioball biofilter system for industrial laundry wastewater treatment

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Abstract: Background: Laundry wastewater contains a range of hazardous substances, including phosphates, surfactants, BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), and TSS (Total Suspended Solids), which can pollute the environment. Thus, effective laundry wastewater management is crucial to reducing negative impacts on water quality and aquatic ecosystems. Objective: We aimed to analyse the effectiveness of small-scale laundry wastewater treatment using electrocoagulation technology combined with a bioball media biofilter. Methods: A quantitative experiment with a one-group pretest-posttest design was used. The tests were conducted on three reactors: Electrocoagulation, a bioball biofilter, and a combination of both, with measurements of physical and chemical wastewater parameters, namely TSS, BOD, COD, and phosphate. Results: The results showed that the combination of electrocoagulation and bioball biofilter technology produced a significant reduction in all parameters: TSS (82.5%), BOD (83.91%), COD (82.27%), and phosphate (97.27%) after 12 hours of treatment. The ANOVA test showed significant differences in TSS ($P = 0.000$) and BOD ($P = 0.036$), but not in COD ($P = 0.290$) or phosphate ($P = 0.619$). Conclusion: The combination of electrocoagulation and bioball biofilters is highly effective for treating laundry wastewater, achieving significant reductions in TSS, BOD, COD, and phosphate levels and meeting stricter wastewater quality standards.

Keywords: laundry wastewater; electrocoagulation; bioball biofilter; TSS; BOD; COD; phosphate; wastewater treatment

1. Introduction

Laundry wastewater can pose serious environmental problems because it contains pollutants such as surfactants, phosphates, and detergent residues that may degrade water quality and harm aquatic ecosystems if discharged without proper treatment [1]. The use of detergents during washing can lead to the accumulation of toxic residues in wastewater. A study showed that the surfactant content in laundry waste can disrupt aquatic ecosystems and increase the potential for eutrophication [2]. The use of environmentally unfriendly detergents contributes to microplastic pollution and hazardous residues that can potentially harm water quality and surrounding ecosystems [2]. Several other studies have shown that COD and phosphate levels in laundry waste can reach very high levels, which, if not treated, can increase the pollution load on water resources [3]. The efficiency of laundry waste treatment has become an important issue due to the increasing volume of waste produced and the potential for environmental pollution. Laundry waste typically contains hazardous compounds, including surfactants, BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solids), and phosphates. Therefore, an effective technological approach is essential to address this problem. Electrocoagulation technology has been identified as a promising method for treating laundry wastewater. Electrocoagulation commonly employs sacrificial electrodes such as aluminium or iron, which generate metal hydroxide flocs capable of destabilizing suspended particles and adsorbing dissolved pollutants in wastewater [4,5]. Research shows that electrocoagulation can significantly reduce surfactant and COD concentrations in a relatively short time compared to biological methods [4]. Furthermore, electrocoagulation offers several advantages, including simple operation, reduced chemical consumption, and the ability to effectively remove colloidal particles, suspended solids, and dissolved organic compounds from wastewater [6,7].

In addition to physicochemical processes, biological treatment technologies have also been widely applied for wastewater purification due to their ability to degrade organic pollutants through microbial activity. One commonly used biological medium is the bioball, which provides a large surface area for microbial attachment and growth. The presence of microorganisms on the bioball surface enhances the biodegradation of organic matter, thereby improving the removal efficiency of pollutants such as BOD, COD, and surfactants. The use of bioballs in combination with electrocoagulation can offer a more efficient solution for laundry wastewater treatment. Bioballs, which are often used in biological filtration systems, can increase the activity of microorganisms in the treatment process, thereby improving the efficiency of pollutant removal [8]. In this combined system, electrocoagulation acts as a primary treatment that destabilizes and removes suspended and colloidal pollutants, while the bioball filter functions as a biological polishing step that enhances the biodegradation of remaining organic compounds. This integration can overcome several weaknesses of the standalone electrocoagulation process, such as decreased electrode efficiency caused by complex coagulation deposits and incomplete removal of biodegradable organic matter [8]. Compared with conventional wastewater treatment methods such as coagulation–flocculation or single biological filtration systems, the integration of electrocoagulation and bioball filtration offers several advantages. These include higher pollutant removal efficiency, shorter treatment time, reduced chemical usage, and improved stability of the treatment process. The synergistic interaction between electrochemical coagulation and biological degradation enables more effective removal of suspended solids, organic

matter, and nutrients from laundry wastewater.

Wastewater treatment technologies such as coagulation–flocculation, filtration, and hybrid systems combining physical, chemical, and biological processes have been widely studied to improve effluent quality and environmental safety [9]. Studies emphasise that integrated treatment systems can enhance pollutant removal efficiency and provide opportunities for wastewater reuse in non-potable applications, thereby supporting sustainability and circular economy principles [9].

Despite these advantages, researchers evaluating the integration of electrocoagulation and bioball biofiltration for small-scale laundry wastewater treatment systems remain limited, particularly in terms of their effectiveness in simultaneously reducing TSS, BOD, COD, and phosphate. Therefore, further research is needed to evaluate the effectiveness of this combined system in removing key pollutants from laundry wastewater. The combination of electrocoagulation technology with bioballs offers significant potential to improve laundry wastewater treatment efficiency, reduce environmental impacts, and meet stricter water quality standards. Therefore, we aim to evaluate the effectiveness of an integrated electrocoagulation and bioball biofilter system for treating small-scale laundry wastewater by analysing the reduction of key pollution parameters, including TSS, BOD, COD, and phosphate. We hope the results of this study will contribute to the development of more sustainable laundry wastewater management strategies and support environmental protection efforts.

2. Materials and methods

2.1. Type and design of research

We employed a quantitative experimental approach to evaluate the effectiveness of electrocoagulation and bioball biofilter systems for treating small-scale laundry wastewater. The experiment used a one-group pretest–posttest design with three treatment configurations: electrocoagulation, bioball biofilter, and a combination of both systems. The treatment performance was evaluated based on reductions in several wastewater quality parameters, including Total Suspended Solids (TSSs), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), phosphate, and pH. Each experiment was conducted in three replications to ensure the reliability and consistency of the results. Laundry wastewater was treated sequentially through different reactor configurations to evaluate the effectiveness of each treatment method individually and in combination. The percentage reduction in each parameter was calculated by comparing values before and after treatment.

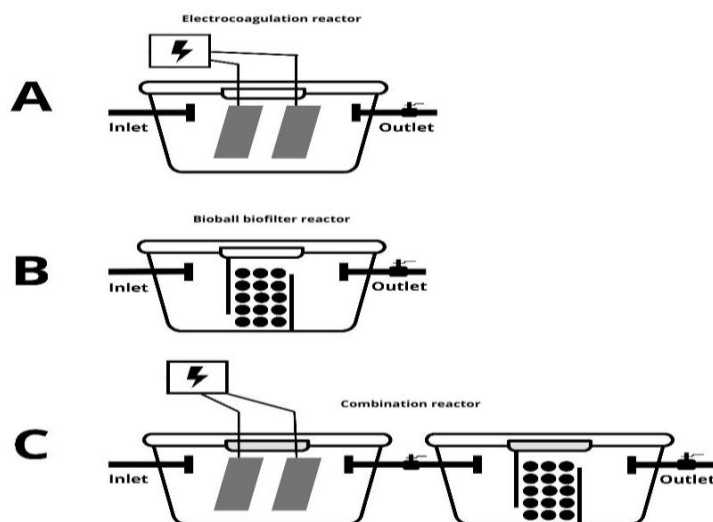


Figure 1. Research Design.

2.2. Research location and time

The research was conducted at the Applied Laboratory and Environmental Health Technology, and analysed at the Makassar Ministry of Health Polytechnic Laboratory, Environmental Health Department. The waste samples used in the research were engineered based on the characteristics of laundry waste that did not meet quality standards. The research was conducted from April to June 2025.

2.3. Research tools and materials

The equipment used in this study included an electrocoagulation reactor made of acrylic with a working volume of approximately 60 L, a biofilter reactor equipped with bioball media, a direct current (DC) power supply (Accurate Power Adaptor STA-8000), aluminium electrodes with a purity of approximately 85–95% and dimensions of 30 cm × 40 cm, bioballs, jerry cans, dippers, a digital pH meter (Smart Sensor AS-218 Digital pH Meter), and other laboratory equipment such as beakers, measuring cylinders, and analytical glassware.

The materials used in this study included laundry wastewater collected from a small-scale laundry facility, as well as laboratory reagents used for water quality analysis. The analysed parameters included physical parameters such as TSS, chemical parameters including pH, phosphate, and COD, and biological parameters such as BOD. All water quality analyses were conducted according to the Standard Methods for the Examination of Water and Wastewater (APHA).

2.4. Treatment process

The electrocoagulation process was carried out using an electrocoagulation reactor equipped with two aluminium electrodes arranged in a parallel configuration inside the reactor. The aluminium electrodes used had dimensions of approximately 30 cm × 40 cm with a purity of about 85–95%. The electrodes were connected to a direct current (DC) power supply (Accurate Power Adaptor STA-8000) to generate the electrical current required for the electrocoagulation process. The distance between the electrodes (electrode spacing) was maintained at approximately 5 cm to ensure a uniform distribution

of electrical current during the treatment process. The applied current produced a current density of approximately 4.17 mA/cm², calculated based on the effective surface area of the electrodes submerged in the wastewater.

Laundry wastewater was introduced into the electrocoagulation reactor until it reached a working volume of approximately 60 L. During the electrocoagulation process, the generated metal hydroxide flocs facilitated the destabilization and aggregation of suspended particles and dissolved pollutants present in the wastewater. After the electrocoagulation treatment, the treated wastewater was subsequently directed to the biofilter reactor containing bioball media for further biological treatment, enabling the remaining biodegradable organic compounds to be removed through microbial activity.

2.5. Data processing and analysis

Data processing involved cleaning the data of measurement and input errors, then analysing it. Descriptive analysis was performed to calculate the average. The analysis and discussion in this study will be presented in the form of tables, graphs, and interpretations, reinforced by ANOVA tests. To determine the efficiency of parameter elimination, the following formula was used:

$$\text{Elimination} = \frac{\bar{X}_{\text{Before processing}} - \bar{X}_{\text{After processing}}}{X_{\text{Before processing}}} 100\% \quad (1)$$

3. Results and discussion

3.1. Effectiveness of TSS Reduction on Electrocoagulation, Bioball Biofilter, and Combination Methods

The effectiveness percentage is calculated as the difference between the levels of each parameter (TSS, BOD, COD, and phosphate) before and after passing through the electrocoagulation unit. A comparison of the effectiveness calculations for each electrocoagulation unit is shown in Table 1.

Table 1. Effectiveness of Electrocoagulation, Bioball Biofilter, and Combination Methods in Terms of Parameters (TSS, BOD, COD, and Phosphate)

No	Parameters	Levels Before (mg/l)	Method					
			Electrocoagulation		Biofilter Bioball		Combination	
			Levels (mg/l)	(%)	Levels (mg/l)	(%)	Levels (mg/l)	(%)
1	TSS	80	16.2	79.75	52.7	34.13	14	82.5
2	BOD	230	139	39.57	97	57.83	37	83.91
3	COD	560	285.3	49.05	168.7	69.88	99.3	82.27
4	Phosphate	55	1.7	96.91	5.8	89.45	1.5	97.27

The results of this study show that the combination reactor achieved the highest TSS removal efficiency (82.5%) compared with electrocoagulation alone (79.75%) and the bioball biofilter (34.13%). This indicates that the integration of electrocoagulation and biological filtration enhances the overall treatment performance. In the electrocoagulation stage, aluminium hydroxide flocs effectively destabilize suspended particles and promote aggregation through charge neutralization and

sweep flocculation mechanisms. Subsequently, the bioball biofilter acts as a polishing unit that captures remaining particles through biological attachment and filtration processes.

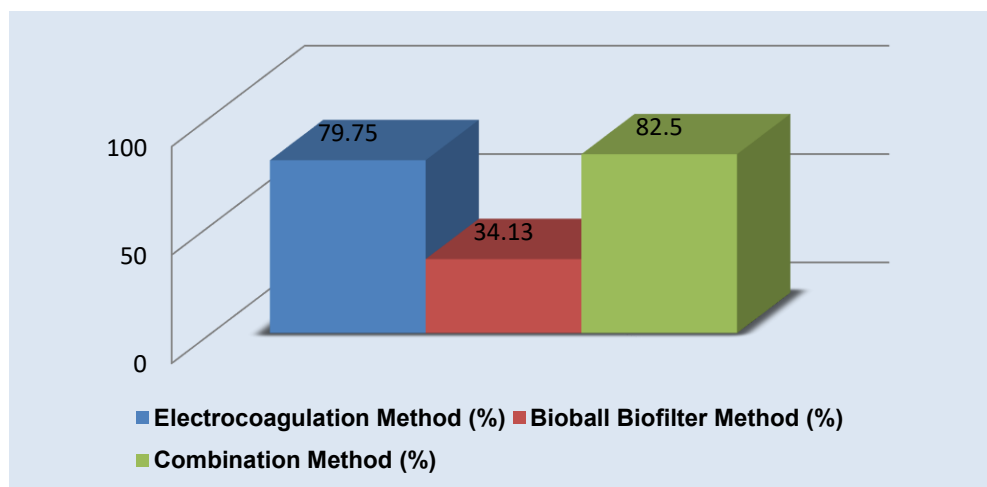


Figure 2. Comparison of the effectiveness of electrocoagulation, bioball biofilter, and combination methods in terms of TSS parameters.

In electrocoagulation, an electrochemical process uses an electric current to remove suspended particles from wastewater. This method has been proven to reduce TSS with excellent efficiency. In a study conducted by Ibrahim B, et al. [10], the electrocoagulation process significantly reduced TSS in fish thawing wastewater, demonstrating high aluminium electrode efficiency. A study [11] showed that biofilters with bioball media can achieve high treatment efficiency, and when combined with electrocoagulation, this method strengthens the initial clarification process by electrocoagulating wastewater before it enters the biofilter, thereby reducing the organic load and increasing the concentration of microorganisms. In the context of laundry wastewater treatment, studies have demonstrated that electrocoagulation can significantly reduce pollutant concentrations. For example, a study on laundry wastewater treatment reported that electrocoagulation was able to reduce COD levels by up to approximately 80%, depending on operational parameters such as voltage and contact time. This finding supports the results of our study, where the electrocoagulation reactor showed substantial reductions in pollutant parameters, particularly in TSS and organic load. Other research conducted by Almomani M H, et al. [12] showed success in reducing TSS levels by more than 90%, demonstrating the vital role of this combination of techniques in treating complex, diverse waste.

Other research was also conducted by García-Morales M A, et al. [13]. In his research, he reported that the integrated electrocoagulation followed by sand filtration achieved a TSS removal rate of approximately 98.05%. This shows that the combination of these two techniques is not only effective but can also produce waste that meets the government-set TSS quality standards. Research that is also in line with this study is research conducted by Habibah K A, et al. [14]. The combination of electrocoagulation and biofilters showed promising results. This study reported that an 82% reduction in TSS can be achieved when the combination method is applied, indicating that the use of biofilters after electrocoagulation can further improve the efficiency of solid particle separation in laundry wastewater. Under Regulation of the Minister of Environment of the Republic of Indonesia Number 5 of 2014, the maximum level of TSS for liquid waste is set at 100 mg/L. This policy is important to ensure environmental quality and protect aquatic ecosystems from pollution caused by industrial and

domestic waste.

In addition to the combination method, we also evaluated the effectiveness of the electrocoagulation method in reducing TSS levels. The graph of the percentage effectiveness of TSS level reduction shows 79.75% effectiveness in reducing TSS over 12 hours of processing. A study [15] showed that TSS reduction efficiency increases with extended contact time, reaching 99.52%. This confirms that contact time plays an important role in the effectiveness of the electrocoagulation method. The bioball biofilter method in this study showed the lowest percentage increase in TSS reduction among the three methods used. Based on the TSS reduction effectiveness calculation, the result was 34.13% after 12 hours of treatment. The results [16] showed that increasing retention time can result in more stable performance in reducing contaminants such as BOD and TSS. It was found that biofilter performance can be maintained at a retention time of 15 days, whereas reducing it to 1.2 days results in a significant decline in system performance.

The reduction in TSS levels in laundry wastewater in this study showed that all three methods effectively reduced TSS. The advantages of each method are as follows: The electrocoagulation method has several significant advantages in reducing TSS levels in laundry wastewater. One of the major advantages is its high efficiency in reducing contaminants [17]. Another advantage of the electrocoagulation method is its ability to treat a wide range of waste types. The results showed that electrocoagulation is effective in treating waste containing contaminants [18]. This method also does not require large amounts of additional chemicals, making it more environmentally friendly than other waste treatment methods. Furthermore, the biofilter method using bioballs has advantages. In the initial measurement of TSSs before treatment, it was found that the TSS level in the laundry waste in this study met the requirements of the Regulation of the Minister of Environment of the Republic of Indonesia Number 5 of 2014. After treatment using three methods with varying time intervals, reductions in levels were observed, and these methods can serve as a reference for treating laundry waste with TSS levels exceeding the set maximum.

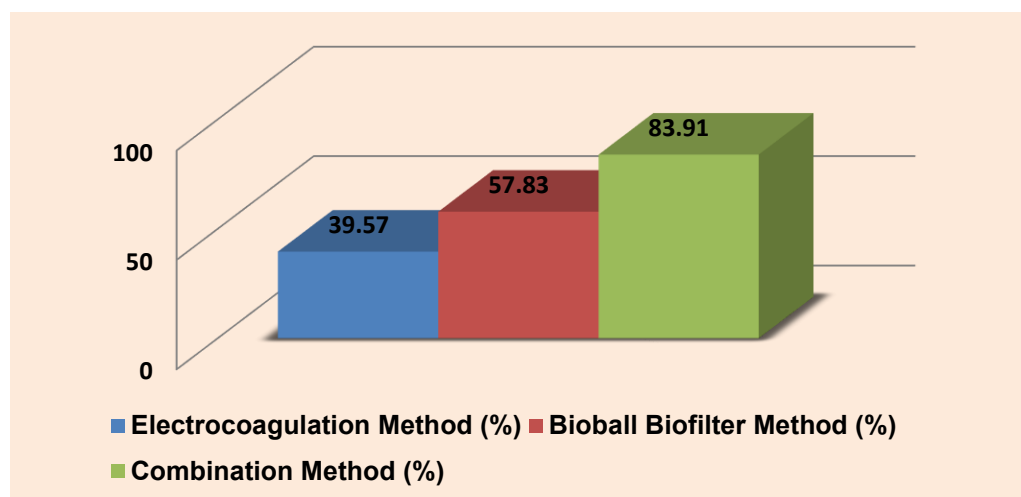


Figure 3. Comparison of the effectiveness of electrocoagulation, bioball biofilter and combination methods in terms of BOD parameters.

The combination of electrocoagulation and a bioball biofilter provides greater waste treatment effectiveness, including laundry waste, by leveraging the strengths of both methods. In the first stage, electrocoagulation removes suspended solids, turbidity, and several large organic compounds that are

difficult to break down by microorganisms through coagulation and flocculation. The coagulants produced in the electrocoagulation system help precipitate large particles and colloids, thereby reducing the dissolved organic load, enabling the subsequent biological treatment stage to be more efficient. The biological process in the biofilter can reduce more complex dissolved organic compounds, such as detergents and surfactants in laundry wastewater, which cannot be completely removed by electrocoagulation alone [19].

In this study, the bioball biofilter method achieved a higher BOD reduction rate than the electrocoagulation method. The bioball biofilter method is more effective at reducing BOD levels in laundry wastewater than electrocoagulation because biofilters rely on aerobic microorganisms to biodegrade dissolved organic compounds, which are the major contributors to high BOD levels. This biological process enables microorganisms to break down complex organic compounds such as detergents, surfactants, oils, and fats commonly found in laundry wastewater, compounds that cannot be fully treated by electrocoagulation [20]. A study by Apema et al. showed that bioballs in aerobic biofilters can effectively reduce BOD levels, achieving up to 85% reduction efficiency [11].

In measuring the BOD level before applying the reduction method in this study, a very high BOD level of 230 mg/l was obtained, whereas the maximum level stipulated in Regulation of the Minister of Environment of the Republic of Indonesia Number 5 of 2014 is 100 mg/l. High BOD levels in laundry wastewater were also found in, revealing [21] that during one year of observation, the average BOD level in laundry effluent reached 445 ± 114 mg/L, which is close to the emission threshold set by environmental regulations. The high BOD content in laundry wastewater has a significant environmental impact, especially on the quality of aquatic ecosystems. When laundry wastewater with high BOD levels is discharged into water bodies without adequate treatment, it can cause problems, including reduced oxygen capacity and damage to aquatic fauna.

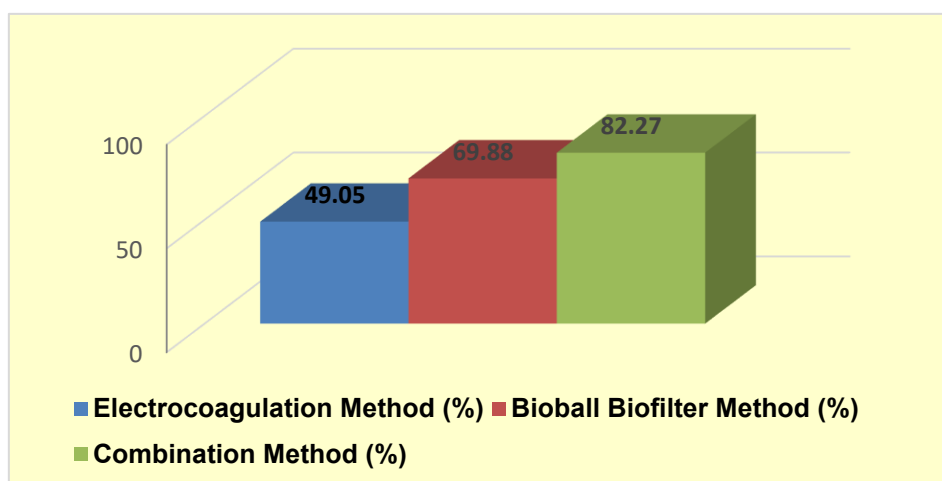


Figure 4. Comparison of the effectiveness of electrocoagulation, bioball biofilter, and combination methods in terms of COD parameters

The COD removal efficiency of the combined system reached 82.27%, which was significantly higher than the electrocoagulation reactor alone (49.05%). This improvement indicates that electrocoagulation effectively reduces the initial pollutant load by removing suspended solids and partially oxidizable organic compounds, while the biological treatment stage further degrades biodegradable organic matter through microbial metabolism. As with the TSS and BOD treatment

results, in this study, the percentage of COD reduction effectiveness showed that the combination method also had the highest percentage value among the other two methods. The combination of biofilters and electrocoagulation enables dual treatment: Biofilters degrade organic matter initially, while electrocoagulation removes finer particles. The results [22] showed that electrocoagulation can achieve COD reductions of up to 86.3% in laundry wastewater.

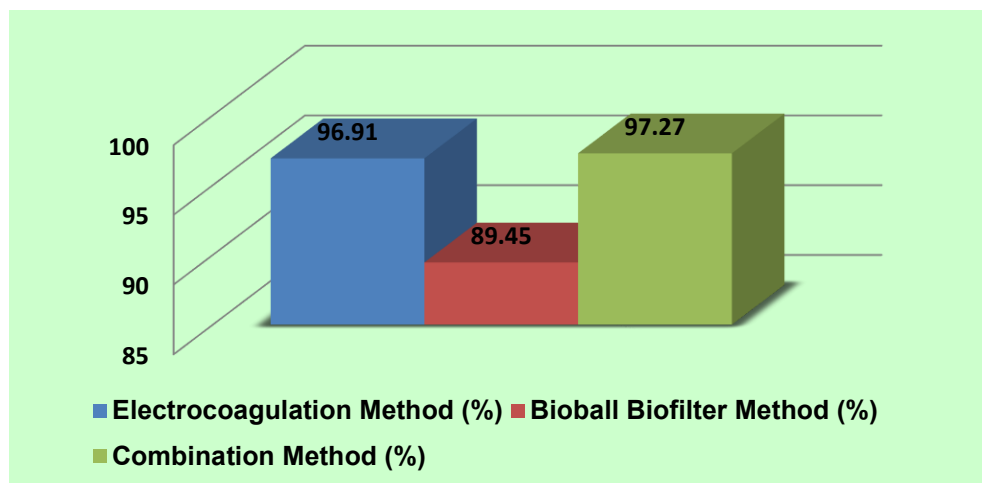


Figure 5. Comparison of the effectiveness of electrocoagulation, bioball biofilter, and combination methods in terms of phosphate parameters.

The graph shows that the combination method is the most effective, achieving a 97.27% reduction in phosphate levels. Next is the electrocoagulation method, with a phosphate reduction rate of 96.91%, showing that it has almost the same treatment capacity as the combination method. Moreover, the bioball biofilter method shows the lowest effectiveness with a phosphate reduction percentage of 89.45%. The results of phosphate reduction using the electrocoagulation method in this study are higher than those obtained with the bioball biofilter method. Laundry wastewater, which is rich in surfactants and detergents, can also interfere with microorganism performance if not pre-treated, so that bioball biofilters alone are often more suitable for COD/BOD reduction than as the main phosphate reduction unit. Moreover, electrocoagulation utilises the presence of phosphate and other ions to form chemical flocs, making it relatively more resistant to variations in organic load and detergent composition. When Electrocoagulation and biofiltration methods are combined, synergy between physical-chemical and biological mechanisms can occur, further increasing phosphate reduction compared to when each method is used separately [23]. In laundry waste management, combining electrocoagulation with biofilters can enhance treatment effectiveness. This research agrees with the studies by Fatimah N, et al [24], which describes the coagulation procedure combined with the biofilter technique, showing that the collaboration between these two methods can yield more efficient phosphate reduction.

3.2. The effect of method variations on laundry wastewater quality

Table 2. ANOVA test Results for variations in electrocoagulation reactors, bioball filters, and combinations.

		Sum of Squares	df	Mean Square	Std. Deviation	F	Sig.
BOD	Between Groups	10732.163	2	5366.082	41.9470	4.197	.036
	Within Groups	19180.257	15	1278.684			
	Total	29912.420	17				
COD	Between Groups	33976.468	2	16988.234	114.6548	1.345	.290
	Within Groups	189500.855	15	12633.390			
	Total	223477.323	17				
Fosfat	Between Groups	182.388	2	91.194	13.1552	.496	.619
	Within Groups	2759.615	15	183.974			
	Total	2942.003	17				
TSS	Between Groups	4522.921	2	2261.461	16.8826	105.194	.000
	Within Groups	322.470	15	21.498			
	Total	4845.391	17				

BOD is widely recognised as a crucial parameter for assessing the level of organic pollution in wastewater. The significant p-value (0.036) indicates that variations in reactor type affect the rate of organic matter decomposition, which alters BOD levels. Studies have shown that BOD is responsive to treatment conditions, which often improve in systems optimised for aerobic decomposition [25]. The reactor's effectiveness may depend on factors such as hydraulic retention time and adequate aeration, which are crucial for determining the microbial activity responsible for organic degradation [26]. On the other hand, TSSs showed a more significant result ($P = 0.000$), indicating that variations in reactor configuration have a strong impact on particulate matter removal. Moreover, high TSS levels in wastewater can cause water-quality problems, including reduced light penetration and habitat degradation in receiving waters [27]. For example, constructed wetlands have been shown to achieve substantial TSS removal efficiencies, often exceeding 80% [28]. These findings suggest that the reactor system employed in this study may have incorporated effective mechanisms, either through physical filtration or biological processes, to substantially enhance TSS mitigation.

The operational mechanisms behind this remarkable performance may include improvements in sedimentation processes across reactor designs or the integration of additional treatment stages to enhance operational efficiency. For example, studies have demonstrated a direct relationship between reactor configuration and the ability to handle fluctuations in influent characteristics, resulting in better TSS control [29]. Therefore, the results of this ANOVA test not only highlight the effectiveness of certain reactor designs in overcoming wastewater treatment challenges but also underscore the need to further explore the optimal reactor configuration for diverse wastewater flows. An examination of reactor variations in laundry wastewater quality, with an emphasis on COD and phosphate levels, revealed important insights into wastewater treatment efficiency. The ANOVA results showed no significant differences in either parameter, with p-values of 0.290 for COD and 0.619 for phosphate. The absence of statistically significant differences indicates that reactor type, under the conditions tested, does not significantly affect pollutant removal efficiency. Studies have highlighted that effective

laundry wastewater treatment typically involves a combination of methods and reactor types. The Moving Bed Biofilm Reactor (MBBR) has been proven to be efficient in reducing COD and phosphorus levels in laundry wastewater, although results may vary depending on specific operational conditions such as hydrodynamic flow rate and the characteristics of the biofilm used [30]. Sugito et al. note that not all reactor types will produce significant differences in efficiency, particularly when comparing configurations that differ little in hydrodynamic forces or biological interactions during processing [31].

Table 3. Results of post Hoc Tests on variations in electrocoagulation reactors, bioball filters and combinations.

Dependent Variable	(I) Reaktor	(J) Reaktor	Mean Difference (I-J)	Std. Error	Sig.
BOD	Elektrokoagulasi	Biofilter Bioball	-31.8833	20.6453	.430
		Kombinasi	-59.7667*	20.6453	.033
	Biofilter Bioball	Elektrokoagulasi	31.8833	20.6453	.430
		Kombinasi	-27.8833	20.6453	.591
COD	Kombinasi	Elektrokoagulasi	59.7667*	20.6453	.033
		Biofilter Bioball	27.8833	20.6453	.591
	Elektrokoagulasi	Biofilter Bioball	-54.06667	64.89322	1.000
		Kombinasi	-106.41667	64.89322	.365
Fosfat	Biofilter Bioball	Elektrokoagulasi	54.06667	64.89322	1.000
		Kombinasi	-52.35000	64.89322	1.000
	Kombinasi	Elektrokoagulasi	106.41667	64.89322	.365
		Biofilter Bioball	52.35000	64.89322	1.000
TSS	Elektrokoagulasi	Biofilter Bioball	4.6167	7.8310	1.000
		Kombinasi	-3.1333	7.8310	1.000
	Biofilter Bioball	Elektrokoagulasi	-4.6167	7.8310	1.000
		Kombinasi	-7.7500	7.8310	1.000
TSS	Kombinasi	Elektrokoagulasi	3.1333	7.8310	1.000
		Biofilter Bioball	7.7500	7.8310	1.000
	Elektrokoagulasi	Biofilter Bioball	31.8833*	2.6769	.000
		Kombinasi	-3.2500	2.6769	.730
Biofilter Bioball	Elektrokoagulasi	-31.8833*	2.6769	.000	
	Kombinasi	-35.1333*	2.6769	.000	
Kombinasi	Elektrokoagulasi	3.2500	2.6769	.730	
	Biofilter Bioball	35.1333*	2.6769	.000	

Electric fields, such as those used in electrocoagulation, can modify or inhibit microbial growth in wastewater treatment systems by disrupting cell adhesion and biofilm formation on media such as bioballs. Although electrocoagulation initially serves to remove pollutants, a side effect of microbial inhibition can occur, leading to a decrease in biological treatment effectiveness if not properly managed [32]. The level of wastewater contamination caused by laundry operations, characterised by high concentrations of surfactants, COD, and phosphates, requires a sustainable treatment methodology that can adapt to fluctuations in influent composition [3,33]. Several reactors, such as

anaerobic baffled reactors and electrocoagulation processes, can achieve varying degrees of success in removing these contaminants; however, this variability does not always translate into statistically significant differences [34]. In this context, the significance threshold set by the ANOVA test ($p > 0.05$) indicated that the selected reactor variations in this study may operate within similar efficiency margins for COD and phosphate removal. This consistency is in line with other findings showing that certain conditions, such as reactor volume, nutrient load, and reactor type (e.g., fixed bed vs. moving bed), can equalise their performance, thus explaining the absence of statistically significant differences observed [35,36]. In addition, research on the application of activated carbon and zeolite across treatment methods demonstrates significant reductions in pollutants. However, it should be noted that statistical significance is not always directly related to operational effectiveness [16]. Factors such as contact time, application method, and reactor implementation scale greatly affect performance but do not always result in significant differences between groups [37].

Post Hoc test results reinforce the ANOVA findings, which showed significant differences in BOD and TSS but not in COD and Phosphate. For the BOD parameter, the Post Hoc test revealed significant differences, particularly between the Electrocoagulation and Combination reactors, with an average difference value of -59.7667 and a significance level of 0.033. This indicates that the electrocoagulation and combined processes show higher efficiency in reducing BOD than the Bioball reactor, most likely due to the coagulation effect and sedimentation capacity provided [38]. However, it is important to note that no significant differences were found between the Electrocoagulation and Bioball Biofilter reactors, nor between the Bioball Biofilter and Combination reactors, suggesting that these treatments may not differ significantly in their ability to reduce BOD levels.

Regarding COD parameters, the Post Hoc test results showed no significant differences among the three reactor types. This aligns with findings from studies on the effectiveness of electrocoagulation systems in treating heterogeneous wastewater, though they do not always show statistically significant advantages over other methods in certain contexts [39,40]. The absence of significant results ($p > 0.05$ in all comparisons) indicates a trend in which traditional methods can perform similarly to electrochemical approaches in COD removal under specified conditions, suggesting that factors such as reactor design and operational parameters play an important role in determining performance [41]. Similarly, in phosphate removal, the data showed no statistical difference between reactor configurations, with all significance values exceeding the 0.05 threshold. This is consistent with literature showing that various electrocoagulation systems may not show significant differences in phosphorus removal efficiency compared to other biochemical processes, especially if optimally designed [42]. Although electrocoagulation has been reported to achieve high phosphorus removal rates in various settings, variability based on operational parameters and wastewater characteristics remains an important factor affecting wider application [43]. Conversely, in the TSS parameter, significant differences were found between reactor variations. The Electrocoagulation reactor showed an average difference value of -31.8833 compared to the Bioball Biofilter reactor, with a highly significant p-value of 0.000, indicating the effectiveness of coagulation action in facilitating floc formation and subsequent sedimentation [44]. Other comparisons, such as between the Bioball Biofilter reactor and the Combination reactor, and between the Electrocoagulation reactor and the Combination reactor, also showed a significant p-value of 0.000. This confirms the effectiveness of electrocoagulation in treating suspended solids in wastewater, which is an important aspect of wastewater management in the laundry sector [39]. However, this study was conducted at a laboratory scale, and further research is required to evaluate the performance of this system under continuous

flow conditions and larger operational scales.

4. Conclusions

We conclude that the combination of electrocoagulation and bioball biofilter technology is effective for treating small-scale laundry wastewater, achieving significant reductions in TSS, BOD, COD, and phosphate. Based on the research objective, to analyse the effectiveness of laundry wastewater treatment, the results show that the combination of electrocoagulation and bioball biofilter methods resulted in a reduction of 82.5% in TSS, 83.91% in BOD, 82.27% in COD, and 97.27% in phosphate after 12 hours of treatment, which is higher than electrocoagulation (TSS 79.75%, BOD 49.05%, COD 49.05%, phosphate 96.91%) and bioball biofilter (TSS 34.13%, BOD 57.83%, COD 69.88%, phosphate 89.45%) individually. The ANOVA test results showed significant differences in TSS ($P = 0.000$) and BOD ($P = 0.036$), but no significant differences in COD ($P = 0.290$) and phosphate ($P = 0.619$). These findings indicate that the combination of electrocoagulation and bioball biofilters provides greater effectiveness in reducing TSS and BOD, and makes a significant contribution to environmentally friendly laundry waste management that meets wastewater quality standards.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare that they have no conflicts of interest

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