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Enhancing Municipal Wastewater Sustainability: Electrocoagulation and Nano-Membrane Filtration

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ABSTRACT

High freshwater consumption by agriculture exacerbates global water scarcity. Water quality is threatened by antibiotic-resistant microorganisms in wastewater. Traditional treatments fail. Electrocoagulation-electro flotation (ECF) and nanofiltration (NF) are promising, cost-effective, and environmentally benign physical-chemical treatment solutions. ECF efficiently neutralises and flocculates pollutants with electricity. EC and NF assessment for municipal wastewater treatment and reuse is essential to solving water scarcity and pollution. This study evaluates the efficacy of an electrocoagulation system (EC) and a NF in treating residential effluents to recover and reuse domestic wastewater and reduce freshwater usage. This study in Al-Kut District, Iraq, uses EC-NF to improve municipal wastewater treatment. The study will analyse the system's pollutant removal, treated water quality, and operating characteristics. The study compares original wastewater characteristics with treated water quality to show that EC-NF systems can improve wastewater treatment and reduce water pollution and shortages in dry places like the Al-Kut District. The project is ethical and should improve municipal wastewater treatment cost-effectively. Mechanical deformation of membrane pores increased pore size, improving organic material transport while decreasing COD removal at higher feed solution temperatures. However, COD removal rates met reuse criteria at 94%-99.4%. Temperature had no effect on BOD removal, whereas operational pressure greatly influenced NH_3 removal efficiency. Rising temperature reduced TDS removal. The study shows that these technologies can cure water but are sensitive to operational conditions. In conclusion, this study examined NF systems for domestic wastewater reuse. Results show the system's pollution removal efficiency and operating parameters' effects.

1. INTRODUCTION

The issue of water shortage throughout the world has been front and centre on the international scene for a long time. As the world's population rises, more water will be needed for agriculture, which now uses around 70.5% of the world's supply. Because of these factors, recycling wastewater for agricultural irrigation makes sense and is a sustainable option [1]. Water reuse is legal in many countries, but there are public health issues about its quality and safety that must be addressed before it can be widely used. Existing standards are inadequate to deal with new pollutants including antibiotic-resistant bacteria and genetic material found in reclaimed water, which is a major cause for worry. Conventional wastewater treatment technologies, according to several studies are insufficient in their ability to eliminate antibiotic-resistant genes and bacteria from treated effluents before they are discharged to landfills or reused [2].

Water scarcity is an urgent worldwide concern, given that agriculture consumes 70.5% of freshwater, a demand that is projected to increase in tandem with the global population [1]. Reusing wastewater for irrigation is feasible; however, antibiotic-resistant bacteria and genes pose water quality concerns. Many conventional wastewater treatments fail to remove these pollutants. Agriculture, industries, commercial entities, institutions, and households produce wastewater with a variety of environmental pollutants [2-4]. Hospital wastewater contains metal oxides, radioactive waste, viruses, germs, and other contaminants. Traditional biological wastewater treatment technologies are expensive, energy-intensive, and may not remove non-biodegradable contaminants. More effective and eco-friendly methods are needed to protect freshwater habitats [5, 6].

In the treatment of municipal wastewater using contemporary physicochemical methods, the removal of "biological oxygen demand (BOD5)", total nitrogen (COD), and phosphate is maximized. In addition, an ultra-filtration membrane was utilized after electrocoagulation pretreatment to get rid of any lingering particles. Therefore, non-edible or woody plants, fish, animals, and sheep may all be farmed using treated wastewater. The results showed that a modest hydro turbine with a 1.5 kwt/h power output and a fluid velocity of 10-15 L/s was able to remove 93%, 95%, and 100% of BOD5, COD, and phosphates, respectively. By turning the micro hydro-turbine with reject flow, 50 percent of the entire energy use may be recovered. Sewage treatment facilities can save up to 50% on construction and running costs when compared to typical, inefficient biological treatment plants. The enhanced suggested approach established via this research produces sludge that is of sufficient quality to be reused as fertilizer, in contrast to the sludge generated by the conventional treatment method, which should not be recycled [7-9].

These issues have led the world to seek novel, cost-effective physical-chemical wastewater treatment technologies. These technologies should be economical, efficient, eco-friendly, easy to manage, and land and energy-efficient. Integrated and hybrid treatments are promising. Advanced wastewater treatment methods, including membrane separation, H_2O_2-derived oxidation, electrochemical oxidation, and sulphate radical-advanced oxidation, have been developed to effectively eliminate emerging pollutants and assure the safety of treated wastewater [10]. Membrane filtration methods including nanofiltration, ultrafiltration, and reverse osmosis are becoming more popular since they balance water quality and energy usage. Successful methods include electrocoagulation-electro flotation (ECF). ECF uses electric current to neutralise contaminants and flocculate them without coagulants. It cuts waste generation and treatment time, making it cost-effective and eco-friendly. Nanofiltration membranes with 1 nm pore sizes are attractive for drinking water, industrial wastewater treatment, and water reuse [11].

They balance reverse osmosis and ultrafiltration, making them energy-efficient and versatile. Nanofiltration is limited in industrial applications compared to reverse osmosis and ultrafiltration, but it has advantages. More frequent membrane changes increase maintenance costs. Nanofiltration systems demand more energy for water treatment, so they must be implemented with energy conservation in mind [12-15]. Optimising energy use and functioning is crucial. Moreover, creative, cost-effective, and environmentally friendly wastewater treatment systems are needed to alleviate global water scarcity. Nanofiltration and electrocoagulation-electro flotation are potential water reuse technologies, however, they must be considered and energy-related issues addressed to be sustainable and safe. Water pollution is a big issue in emerging nations like Iraq [16-19]. The biggest issue is providing clean drinking water nationwide. Farmers and consumers utilise treated water. Due to rising manufacturing and human pollution, water pollutants pose several risks [20-22]. Polluted water causes various ailments, including stomach cancer, due to heavy metal bioaccumulation from industrial wastewater discharge.

Traditional water pollution treatment focuses on nutrients, suspended particles, and natural treatment. Sludge, heavy metals, and growing plastic pollutants from households and industries cannot be treated by these approaches. Thus, conventional approaches fail to handle today's wastewater, which contains new pollutants and compounds. However, it is expensive, time-consuming, and requires more professionals that are experienced. Therefore, membrane bioreactor techniques are recommended to eliminate developing wastewater pollutants [23, 24].

There are discharge restrictions on the adsorption and nanofiltration technologies. Thus, in recent years, there has been a lot of interest in electrochemical techniques such electro-flotation (EF), electro-kinetic remediation, electrocoagulation (EC), and electro-oxidation (EO). Their minimal chemical consumption and accessibility of availability are the main reasons for their appeal. Specifically, EC is a fairly dependable means of eliminating pollutants from wastewater, in contrast to other methods [7, 25]. According to recent research, especially at higher concentrations, EC efficiently eliminates contaminants found in groundwater, including TDS, chlorides, sulphates, potassium, calcium, magnesium, and sodium. Recent developments have made EC equipment portable, allowing it to be quickly customized to fit industry requirements and readily provide current and voltage data for efficiency monitoring [26-28].

Since its invention a century ago, EC has been used to efficiently treat wastewater from a range of sources, including steam cleaners, meat and poultry processors, textile production companies, and metal platters [1, 29]. However, because electricity and investment were so expensive at the time, EC was not commonly used for water purification. When EC was shown to be more effective than traditional chemical coagulation in eliminating both organic and inorganic pollutants from surface and groundwater, it began to acquire notoriety. In the Iraq, electrocoagulation was first applied to treat sizable amounts of drinking water in 1994 [30].

Emulsified oils, bacteria, heavy metals, and suspended solids (TSS) may all be removed from water using the sophisticated EC process. It is a synthesis of well-known methods including flotation, coagulation, and electrochemistry. On the other hand, the literature on combining the three techniques is quite thin [31-33]. In the twentieth century, the electrochemical process had little acceptance and success despite being a competitive and effective wastewater treatment method.

The present study evaluated wastewater treatment by EC and NF methods. Newer methods offer pros and cons to promote effective fouling prevention treatment. Many researchers must learn how to incorporate electrocoagulation, something that has not been explored yet. There is a research gap between innovative wastewater treatment systems so we in turn will evaluate EC and NF for municipal wastewater treatment and reuse and statistically compare their efficiencies to determine their significance. The specific goal of this research is to enhance the efficiency of a domestic wastewater recycling and reuse system through the use of an Electro-Coagulation (EC) system and a Nano-Filtration (NF) membrane to reduce the need for potable water. It can be predicted the efficiency of these two methods and obtained effective treatment results.

2. EXPERIMENTAL METHOD

2.1 Research design

This chapter delves into the specifics of the treatment approach and the materials used to obtain high removal efficiency with municipal wastewater samples gathered from the Al-Kut District/Al-Jihad neighborhood in the Wasit Governorate of Iraq. We also provide a detailed description of the apparatus and the experimental setup, illuminating how each piece of equipment performed. Experiment participants used plant facility samples treated with the EC-NF technique. Readers interested in learning more about the research process and the methods used to effectively treat and reuse municipal wastewater will find this chapter an invaluable resource. In a municipal area of Iraq, a 10-gallon water sample was collected from a canal and kept in a dark location at 5°C during experimentation.

The water had a slightly alkaline pH of 7.6 ± 0.18 and moderate turbidity measuring 17.6 ± 1.0 NTU. The sample contained moderate amounts of organic matter of natural origin, with dissolved organic carbon (DOC) measuring 6.87 ± 0.29 mg/L and UV254 measuring 0.150 ± 0.008 cm^{-1}. The water was low in conductivity (387.4 ± 15.0 μS/cm), soft, with total hardness measuring 58 ± 3.1 and calcium hardness measuring 54.21 ± 2.1 mg/L as $CaCO_3$, and had small buffering capability (alkalinity 83.5 ± 3.1 mg/L as $CaCO_3$). During the course of the investigation, the standard deviation for all assessed water quality parameters remained within 5%, ensuring consistent results across different experiments conducted with this sample.

This study optimizes municipal wastewater treatment in Al-Kut District, Iraq, using Electrocoagulation-Nano-filtration (EC-NF). These goals are to evaluate this system's ability to remove contaminants from wastewater, assess the treated water's quality for reuse, and optimize operational parameters for optimal treatment efficiency [34]. Electrocoagulation and nano-filtration will treat Al-Kut District wastewater samples after pre-screening for big particles [35].

During treatment, BOD, COD, TSS, DO, TDS, EC, colour, and pH will be measured. This research compares original wastewater characteristics with treated water quality to demonstrate how EC-NF systems might improve wastewater treatment and alleviate regional water pollution and scarcity. This work could solve water contamination issues in desert areas like Al-Kut District. It examines how EC-NF technology can treat municipal wastewater cost-effectively and sustainably [36-38].

The research should provide a complete understanding of the system's functioning, enabling wastewater treatment advances for similar water quality issues [39]. The 12-month research will include sample collection, experimentation, data analysis, and reporting. The project will follow ethical guidelines, including getting permission and guaranteeing staff safety. After this research, the optimised EC-NF system should increase the quality of treated wastewater, making it eligible for reuse and lowering regional water resource strain.

2.2 Inclusion and exclusion criteria

2.2.1 System configurations

An electrolytic cell with a cathode and an anode that are externally linked to a power source and submerged in an electrolytic solution makes up the EC system. An anode experiences oxidation and the metal dissociates into divalent or trivalent metallic ions, releasing an equivalent number of electrons, as the current flows through the electrolytic cell. Dissolution only takes place at the anode, despite the fact that both electrodes are made of the same substance [40]. The electrospun nanofiber surface was coated thinly with polyamide to create the NF membrane system. With more water flowing across it, the NF membrane showed a higher rate of salt rejection. It was more effective in rejecting magnesium's divalent cations and sulfate anions.

2.2.2 Sample preparation

By forcing water through the semipermeable NF membrane and raising the pressure on the salt side of the membrane, nanofiltration (NF) removes nearly all dissolved salts from the reject stream. Moreover, it can simultaneously lower monovalent ions by 60-80%. An effective method of treating residential wastewater is called electrocoagulation (EC), in which coagulants are created at the sacrificial anode by in-situ electrolytic oxidation. It functions by taking consistent sample volumes at intervals of time that are proportionate to the flow of wastewater. In the alternative approach, the sample is obtained by keeping a fixed time interval between each aliquot while adjusting its volume in proportion to the flow.

2.2.3 Inclusion

This study relies on municipal wastewater samples from the Al-Kut District / Al-Jihad neighbourhood, Wasit governorate, Iraq. Municipal wastewater samples with modest organic matter levels, turbidity, and pollutants. This research focuses on Electrocoagulation-Nanofiltration (EC-NF)-treated samples. Water quality samples with BOD, COD, TSS, DO, TDS, EC, colour, and pH data.

2.2.4 Exclusion

Wastewater samples from outside Al-Kut District/Al-Jihad neighbourhood municipal locations. Samples without EC-NF treatment, as the focus is on its efficiency. Samples where water quality parameters are missing or incomplete are necessary for EC-NF system evaluation.

2.3 Analytical method

The statistical analysis for this study is used different methods. Water quality metrics including BOD, COD, TSS, DO, TDS, EC, colour, and pH were summarized using descriptive statistics. Hypothesis testing, t-tests was used to compare pre- and post-treatment values to determine how the EC-NF system affects wastewater quality. Correlation and regression analysis highlight variables' interactions and forecast operational parameters' effects. ANOVA also used to compare treatment conditions. These statistical tools revealed that the EC-NF system's wastewater treatment is efficient.

3. RESULTS

The process of mechanical deformation of membrane pores, which increases pore size, aids transport of organic molecules across membranes. As the feed solution temperature increases, the elimination rates of "chemical oxygen demand (COD)" decrease. The decrease in total "chemical oxygen demand (COD)" reduction from 25°C to 37°C is seen in Figure 1. Complete clearance rates from the membrane were between 94% and 99.4%, which was regarded sufficient for maintaining COD. It was decided that a COD elimination rate of 90.3% was adequate for reuse given the rates under consideration.

Figure 2 shows how operating pressure affects NH_3 removal rates overall. The results of this investigation show that the efficiency with which NH_3 is removed is directly related to the operating pressure. The increased pressure applied to the NH_3 membrane can be attributed to the observed correlation because it increases the driving force and decreases resistance across the membrane's surface, therefore relieving membrane compaction. When operating temperatures rise from 25°C to 37°C and pressures remain at 2 and 10 bars, total NH_3 removal decreases.

Figure 3 displays the efficiency with which NF membranes eliminate BOD. Comparison of total BOD removal at two different working temperatures (25°C and 37°C) and two different pressures (2 and 10 bars) is shown. Noting that the effectiveness of BOD removal tends to decrease with increasing temperature is important, even if the observed impact is quite small. The particle size distribution in the wastewater samples explains why NF membranes are so efficient in separating BOD. Previous investigations have revealed that the particles responsible for BOD readings are often bigger than the pore size of the membranes utilised.

Figure 4 compares the effects of two different feed temperatures (25°C and 37°C) and two different pressures (2 bar and 10 bar) on the efficiency with which the "Nano Filtration (NF)" membrane removes "total dissolved solids (TDS)". The overall efficiency of the "Nano Filtration (NF)" membrane in decreasing "total dissolved solids (TDS)" decreases as feeding temperature rises. Mechanical deformation, leading to an increase in pore size inside the membrane, is responsible for the observed phenomena [41-43]. Dissolved particles are able to flow through the membrane because of this enlargement. The membrane's effectiveness in removing "total dissolved solids (TDS)" is notable, with removal rates ranging from 79% to 88%, while undergoing oscillations.

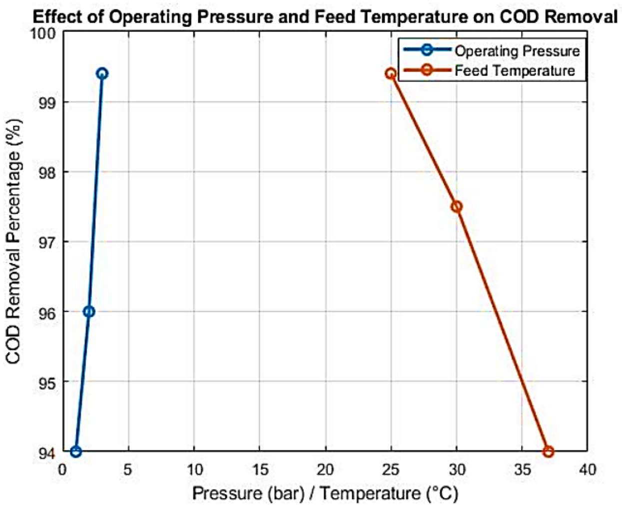

Figure 1. Impact of OP and FT on COD removal

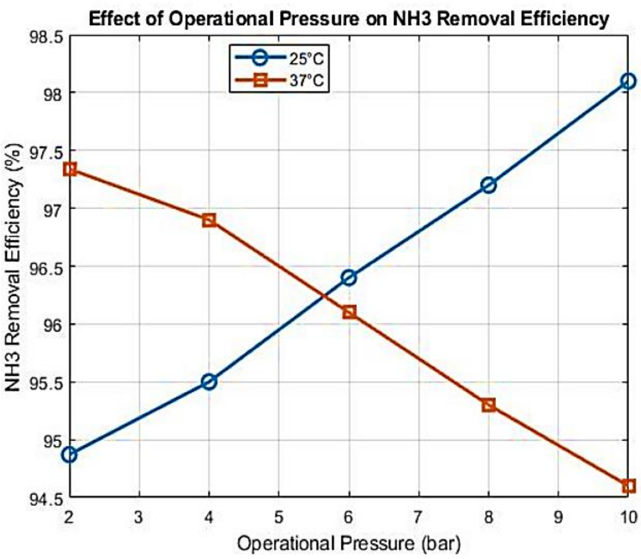

Figure 2. Impact of OP on NH_3 removal

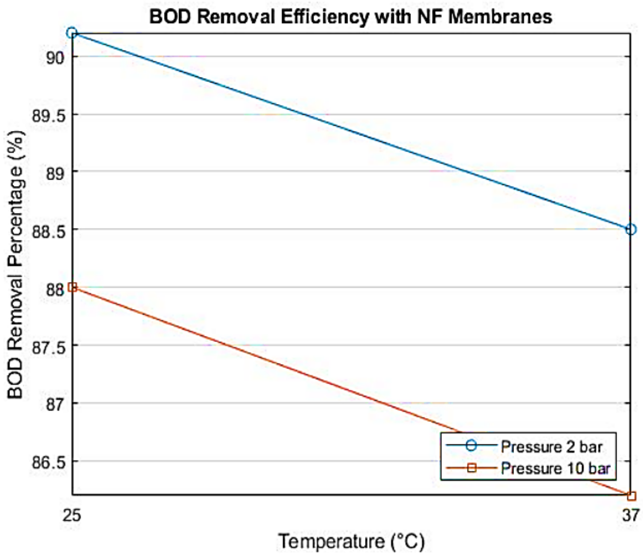

Figure 3. Impact of OP on BOD removal percentage

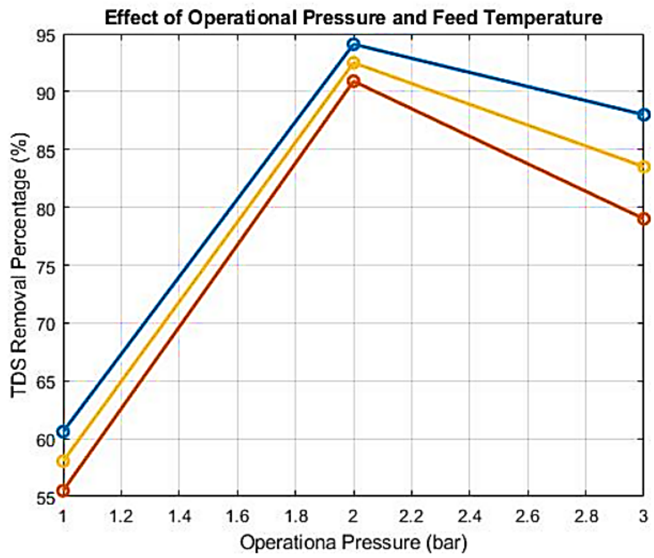

Figure 4. Impact of operational pressure on TDS removal

Table 1. Comparison of EC-NF parameters with water reuse

Parameters	EC-NF Effluent	Water Reuse Standard
BOD (mg/L)	≤15	0-40
COD (mg/L)	≤20	0-100
Turbidity (NTU)	0	≤15
TSS (mg/L)	0	≤145
TDS (mg/L)	≤60	≤500
pH	≤8	6-8

Table 1 compares EC-NF (Electrocoagulation-Nanofiltration) effluent properties to water reuse standards. Assessment of treated water quality and reuse depends on these characteristics. The BOD for EC-NF effluent should be 15 or less, indicating minimal organic contaminants. As the treatment procedure reduces organic and inorganic pollutants, the Chemical Oxygen Demand (COD) should be below 20. To provide clean, particle-free water, EC-NF effluent turbidity should be zero [44]. The treated water should have less than

145 mg/L of total suspended solids (TSS). To indicate low dissolved minerals and salts, Total Dissolved Solids (TDS) should be 60 mg/L or below. Finally, the pH of the treated water should be 6-8 for reuse. This shows that the EC-NF process may produce water that meets or exceeds water reuse standards, making it a potential solution for sustainable water resource management and conservation.

Table 2. Evaluation details for EC

Objective Responses	Constants (a0, a1)		Correlation Coefficient (R)
COD Removal	74.999	6.292	0.734
BOD Removal	75.752	6.752	0.873
NH_3 Removal	72.48	6.92	0.836
TSS Removal	92.431	3.048	0.753
Turb. Removal	88.941	5.056	0.884
Permeate Flux	0.583	-0.208	-0.969

In Table 2, the removal efficiencies and correlation coefficients (R) for several water quality metrics are evaluated for the Electrocoagulation (EC) method. The constants (a0 and a1) impact operations. We found that the EC technique significantly reduces various water pollutants. It removes Chemical Oxygen Demand (COD) with 74.999% efficiency, reducing organic and inorganic contaminants. Reducing organic pollution requires good BOD removal, which it does at 75.752%. Ammonia (NH_3) removal is 72.48%, demonstrating its ability to reduce this pollutant. EC also removes 92.431% and 88.941% of TSS (total suspended solids) and turbidity, reducing solid particles and cloudiness in the water. BOD and Turbidity removal had significant correlation values (0.873 and 0.884, respectively), indicating a strong link between process factors and removal efficiency [45]. The Permeate Flux and its negative association with constants and COD elimination (-0.969) suggest membrane fouling or flux drop during the EC process. The results in Table 2 show that the EC process may enhance water quality and remove contaminants, although permeate flux concerns must be addressed for maximum performance.

Table 3. Evaluation details for NF

Objective Response	Constants (a0, a1)		Correlation Coefficient (R)
COD Removal	101.008	0.309	-0.183
BOD Removal	94.548	0.705	-0.09
NH_3 Removal	89.275	0.503	-0.11
TDS	86.02	86.02	86.02
Permeate Flux	20.675	1.467	0.504
Variable	**Mean**	**Std. Deviation**	**N**
COD Removal	84.4373	3.6242	15
HRT	1.5	0.42258	15

Table 3 evaluates nanofiltration (NF)'s capacity to remove water quality factors, the correlation coefficient (R), and critical variables. Operational factors are a0 and a1. NF removes COD (Chemical Oxygen Demand) with 101.008% efficiency, reducing organic and inorganic contaminants. The negative correlation value (-0.183) for COD removal shows a more complex link between process factors and removal efficiency. NF also performs well in BOD (biological oxygen demand) and ammonia (NH_3) removal, with efficiencies of 94.548% and 89.275%, respectively, despite negative correlation coefficients indicating complex relationships between variables and removal efficiency.

The TDS measurement stays at 86.02, demonstrating NF does not influence dissolved mineral and salt concentrations. The increased permeability flux (20.675) indicates that NF permits water to move through the membrane faster. The supplementary variable data shows COD Removal, HRT (Hydraulic Retention Time) mean, and standard deviation, revealing their statistical distribution. In conclusion, NF may remove COD, BOD, and NH_3 while maintaining high permeate flux. The negative correlation coefficients and continuous TDS imply that more research and optimisation may be needed to understand and improve the NF process.

Table 4 shows COD elimination regression analysis versus Hydraulic Retention Time. The Pearson Correlation coefficient of 0.734 suggests a relatively significant positive linear association between COD elimination and HRT. The regression model's R Square value of 0.538 shows that HRT fluctuations explain 53.8% of COD removal variation. A 15.152 F-statistic and 0.002 p-value (Sig.) make the regression model statistically significant, below the 0.05 significance level. This suggests HRT greatly affects COD elimination. HRT increases COD elimination by 6.292 units per unit, according to the unstandardized coefficient. The table shows that HRT is a major component in COD elimination, and the model's significant F-statistic and correlation coefficient imply that it is accurate [46].

Table 4. Coefficients for COD removal

Object	Pearson Correlation						
COD	1						
HRT	0.734						
Model	R	R Squ.	Adjusted R Sq.	Std. Error of the Estimate			
1	0.73	0.58	0.503	2.55575			
Model	Sum of Sq.	df	Mean Square	F			Sig.
Reg.	98.9	1	98.973	15.152			0.002
Residual	84.9	13	6.532	-	-	-	-
Total	183	14					
Model	*1	*2	B	Std. Error	Beta	t	Sig.
1(Const)	74.99	-	29.847	2.51	-	-	0
HRT	6.29	0.73	3.893	0	-	-	0.2

*1 Unstandardized Coefficients
*2 Standardized Coefficients

Table 5 shows pressure, temperature, and COD removal correlation and regression results. Pressure and COD removal is strongly correlated (0.617) while Temperature and COD Removal is much greater (0.992). As shown by the excellent R Square value of 0.985, the regression model for COD Removal based on pressure and Temperature is robust and explains 98.5% of the variance. Pressure and Temperature strongly affects COD Removal, as shown by the model's F-statistic of 223.698 and statistically significant ($P < 0.05$). The unstandardized coefficients show that pressure increases COD Removal by 0.309 units and Temperature decreases it by 0.183 units. This table shows that pressure and Temperature significantly affect COD Removal and that the regression model based on these factors is highly predictive.

Table 5. Findings of correlations in this study

Variable	Pres.			Temperature			
COD Removal	1			0.617			
Pressure				1			
Model	R	R Sq.	Temperature Adjusted R Sq.	Std. Error of the Estimate			
1	0.992	0.985	0.98	0.2098			
Model	Sum of Sq.	df	Mean Square	F		Sig.	
Regression	19.692	2	9.846	224		0	
Residual	0.308	7	0.044				
Total	20	9					
Model	*1	*2	B	Std. Error	Beta	t	Sig.
1(Cons.)	101.01	0.376	268.33				0
Pressure	0.309	0.023	0.617	13	0		
Temp.	-0.183	0.01	-0.777	-17	0		

4. DISCUSSION

The experimental results in this section focus on Hydraulic Retention Time (HRT), current density, operational pressure, and feed temperature in the Electrocoagulation (EC) and Nano Filtration (NF) processes for contaminant removal [13, 14]. Various findings illuminate the efficacy of various treatment technologies in real-home wastewater and their water reuse potential. As HRT and current density increased, so did COD and BOD elimination in the EC process. This showed that longer exposure times and greater current densities enhanced treatment efficiency.

Due to aluminium electrode corrosion, removal efficiency decreased slightly over time. While reducing efficiency, this corrosion nevertheless achieved adequate removal rates [15, 16]. The EC technique removed nitrate (NO_3) from wastewater, with longer electrolysis periods improving efficiency. The EC process's highest removal effectiveness of 15.2% was obtained in 5 minutes, highlighting the necessity of electrolysis time. Operational pressure and current density significantly affected removal efficiency, underscoring their importance [17-20]. The EC procedure removed phosphate (PO_4) at about 93% efficiency. Increased current density and electrolysis time improved metal dissolving and $AlPO_4$ precipitation. These data show that the EC technique may remove phosphate from wastewater [21]. In total suspended solids (TSS) removal, the EC procedure was effective at 60%. The variation in removal efficiency may be due to current density. TSS removal effectiveness improved with current density. These findings show how operational conditions, particularly current density, affect TSS elimination [22, 23].

The NF system produced water reuse-compliant permeate; however, several parameters needed correction. Reclaimed water has higher EC, TDS, BOD, COD, and NH_3 levels than allowed. After removing remaining contaminants and organic substances, the NF system ensured water quality met reuse standards. Removal rates and permeate flow depended on operating pressure and input temperature [24]. Operating pressure has a significant impact on NF system COD elimination. Higher operating pressure reduced organic material permeability, improving wastewater treatment membrane efficiency. High membrane surface density increases chemical oxygen demand (COD) removal efficiency. Increased feed temperature deformed membrane pores, allowing organic molecules to pass through, reducing COD removal. Yet, the NF system removed 94% to 99.4% of COD [28, 40].

Operating pressure in the NF system greatly affected wastewater NH_3 removal. Pressure on the NH_3 membrane increased driving force and lowered surface resistance, improving removal efficiency. When pressures were 2 and 10 bars, NH_3 removal decreased with temperature. These findings support previous research and emphasise the importance of operational parameters in NH_3 removal [46]. BOD removal was efficient using the NF system even at high starting concentrations. Feed temperature did not affect BOD removal, however, efficiency decreased with temperature. Due to wastewater particles being larger than membrane pores, NF membranes removed BOD effectively. The NF method reduced BOD from home sewage samples. With removal rates of 79% to 88%, the NF system reduced total dissolved solids (TDS). Due to increased driving power and lower resistance, operating pressure increased TDS removal efficiency. Mechanical deformation of membrane pores reduced TDS removal effectiveness as feed temperature increased. NF produced high TDS removal rates despite these oscillations.

Existing NF technology has limitations in efficiently decreasing TDS and attaining effluent concentrations that exceed reuse criteria, thus the introduction of NF (Nano Filtration) membranes has become vital in tackling excessive "Total Dissolved Solids (TDS)" levels in household sewage effluent. In order to effectively recover and reuse wastewater, it is crucial to combine NF and "Nano Filtration (NF)" treatments. Since the quantities of "total dissolved solids (TDS)" in domestic wastewater are quite close to the secondary drinking water quality limits, NF membranes provide a viable alternative for the purpose of water reuse. The primary objective of the NF application is to lessen the amount of organic matter present, which includes harmful microorganisms. Incredibly, NF membrane modules have been shown to be highly effective at removing both general and specific ions that contribute to "total dissolved solids (TDS)" measurements, such as calcium, magnesium, nitrate, chloride, carbonate, and sulphate. Figure 1 shows a graph showing how operating pressure affects the rate at which "total dissolved solids (TDS)" are removed from a solution. There is a positive relationship between operating pressure and TDS removal efficiency. The reason for this connection is that increasing driving power correlates with increased pressure applied to the NF membrane, which in turn reduces resistance across the membrane's surface and relieves membrane compaction.

When comparing two distinct temperatures (25°C and 37°C) and two different pressures (2 bar and 10 bar), it becomes clear that the "Nano Filtration (NF)" membrane's removal efficiency of "total dissolved solids (TDS)" decreases as the feed temperature increases. When the feeding temperature rises, the membrane's ability to remove "total dissolved solids" (TDS) is diminished. Mechanical deformation, leading to an increase in pore size inside the membrane, is responsible for the observed phenomena. Dissolved particles are able to flow through the membrane because of this enlargement. Although the membrane's removal rate for "total dissolved solids (TDS)" fluctuates from 79 to 88%, it is still impressive. The current results are in line with those of other investigations [8], lending credence to the widespread contentment with the membranes purported capacity to lower "total dissolved solids (TDS)".

The "chemical oxygen demand (COD)" of the initial influent ranged from 450 to 500 mg/L during the duration of the 12-hour HRT experiment. Figure 1 shows the % reduction in COD that might be accomplished by using the EC method. The average elimination rate of "chemical oxygen demand (COD)" was found to be 62% within the setting of a 12-hour "hydraulic retention time (HRT)". The lowest removal rate ever reported was 58.3%, with 63.6% being the highest.

When run with a 12-hour "hydraulic retention time (HRT)", the NF process showed a mean "chemical oxygen demand (COD)" removal rate of 77%. The percentage of candidates eliminated was between 71.1% and 83.8%. The overall efficiency was significantly improved once the EC and NF systems were combined. COD elimination efficiency of 89.3% (minimum) to 93.6% (highest) were demonstrated using the integrated "electrocoagulation-membrane bioreactor (EC-NF)" system. During normal EC-NF system functioning, the lowest effluent concentration recorded was 31 mg/L.

Higher operating pressure increased permeate flux in the NF system. This was due to higher driving force and reduced membrane surface resistance. Increased feed temperature reduced feed viscosity and increased diffusion, improving permeate flux. These studies showed that operating pressure and feed temperature affect permeate flux [33-35]. Both the EC and NF systems showed a gradual decrease in permeate flux over time due to membrane fouling by precipitated chemicals. This highlights the importance of maintenance and cleaning to maintain treatment efficiency. The comparison examination of (EC-NF) treated water with water reuse criteria showed that NF-NF technology might reduce environmental pollution and encourage water reuse. The NF-NF permeates met agricultural irrigation standards, making them suitable for water reuse. This method reduces freshwater use and addresses environmental issues sustainably [31]. The statistical study, conducted with SPSS, used multiple regression models to assess how different parameters affected COD, BOD, NH_3, TSS, turbidity, and permeate flow in both the NF and NF systems. The correlations between these parameters and removal efficiency were fully explained by this approach, providing useful insights for wastewater treatment research [35-40].

We suggested a pilot-scale integrated EC and NF system as a pretreatment in order to provide a small, controllable treatment solution. More than 3000 L may be generated every day in this stage, greatly enhancing the quality of the water. These findings demonstrate the less-studied integrated treatment's (EC-NF) scalability potential for produced water treatment. The feasibility of the integrated strategy for larger-scale, sustainable produced water treatment is therefore suggested by this study.

5. CONCLUSION

In conclusion, this research shed light on NF system treatment and reuse of domestic wastewater. The findings emphasise operational aspects of pollutant removal and permeate flux. Local wastewater treatment for reuse was the focus of the experiments. The experiments used a larger "Nano Filtration (NF)" system instead of the pilot-scale one. The study showed the NF system's extraordinary power to clean residential wastewater. In a 2-day "Hydraulic Retention Time (HRT)", the system removed 99.2% it was extremely turbid (99.6% TSS), had a chemical oxygen demand of 91.6%, contained 88.6% ammonia, and required 91% biochemical oxygen. Clearance rates were found to be closely related to "hydraulic retention time (HRT)" and "mixed liquid suspended solids (MLSS)", indicating that both factors contributed to improved removal effectiveness. Integrating the NF system with the larger NF system showed great efficiency in residual pollutant removal, reuse criteria, and pre-treatment. With average total removal efficiencies of 88.3% to 99.6%, residual pollutants like COD, TDS, NH_3, and BOD were continuously removed at optimal levels. Operating pressure linearly increased total elimination rates for BOD, COD, TDS, and NH_3, according to the study. The study found that operational temperature decreased removal efficiency, demonstrating that temperature affects treatment. It is acknowledged that electrocoagulation (EC) has been a successful technique for more than a century due to its vast variety of applications in the treatment of wastewater. It is highly cost-effective and leaves some important indicators unaffected because no chemicals, coagulants, or flocculants are needed for the treatment procedure. However, electrocoagulation is a multi-step, intricate process that can be advantageous as well as challenging, compared with Nano-Filtration (NF). The development of NF equipment was prompted by a broad range of possible processes, some of which have only been examined in lab settings. The usefulness of this equipment has not yet been thoroughly examined on an industrial scale. These operational parameters affect the NF system's performance since operating pressure and feeding temperature were positively correlated with permeate flux. SPSS found high correlations between COD, BOD, NH_3, TSS, turbidity, and permeate flux removal. Additionally, operating pressure significantly correlated with pollutant removal rates and permeate flux, with efficiencies exceeding 99% ($p < 0.05$). In this study, the chemical and molecular elements that are important in determining the quality of treated water were not addressed.

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