Migration Letters

Volume: 21, No: S10 (2024), pp. 369-379

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)
www.migrationletters.com

Innovative Solutions For Municipal Wastewater: Electrocoagulation And Nano-Membrane Filtration Technologies

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Abstract

The extensive use of water in agriculture stresses the ecosystem and increases concerns about a potential water catastrophe in the future. One example of a sustainable approach is using wastewater for irrigation. New contaminants, however, are dangerous to the environment and public health because they can't be removed with standard treatment techniques. Energy-efficient physicochemical processes, such as electrocoagulation-electroflotation and nanofiltration, have the potential to reduce water pollution and expand the availability of clean water. In order to eliminate pollutants, enhance water quality, and support sustainable resource management, this study looks at the novel municipal wastewater treatment methods of electrocoagulation (EC) and nano-membrane filtration (NF). This year-long project aims to implement sustainable wastewater treatment methods at a hospital. The process entails gathering wastewater, filtering out solids, and treating the wastewater with an EC-NF system. The measurement of treatment methods' efficiency is done using anion/cation analysis, pH, BOD, COD, and TDS. This research aims to promote ecologically friendly wastewater treatment systems to improve water quality and save resources. The study assessed EC performance. EC showed high correlations and R values [1]for COD (97.181% removal), BOD (97.4% to 88% at 25°C, 88.5% to 86% at 37°C), NH_3, TSS, and turbidity reduction, indicating efficient pollutant removal. TDS and permeate flux were minimally affected. Hydraulic Retention Time modestly improved COD elimination with low p-value. Pressure (6 bar, R = 0.992) positively influenced COD removal, while Temperature (31°C, R = -0.183) negatively affected efficiency. Further investigation is needed for the relationship between pressure and BOD removal. This study shows that NF removes pollutants from home sewage effectively. Operational parameter optimization enhanced wastewater treatment removal rates, proving its practicality and importance.

Keywords: Agriculture, Electrocoagulation-Nanofiltration, Contaminants, Wastewater.

1. INTRODUCTION

Water scarcity is a global issue due to the extensive usage of fresh water in agriculture. The need for water for agriculture will increase as the world's population rises. It is sustainable to recycle wastewater for agricultural irrigation in light of these limitations [1]. The safety and quality of reclaimed water have come under scrutiny, particularly in light of the emergence of novel contaminants such as genetic material and bacteria resistant to antibiotics, which can't be eliminated by existing wastewater treatment methods [2, 3]. The environment and public health could be harmed by this. Numerous dangerous pollutants

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can be found in wastewater from homes, businesses, industries, and agricultural practices. Heavy metals, radioactive elements, hazardous liquid waste, viruses, d other things can be found in hospital wastewater [4, 5].

Traditional biological wastewater treatment struggles to break down non-biodegradable contaminants. Moreover, these biological treatment facilities have high upfront and ongoing expenses, substantial power consumption during aeration, and equipment shortages [5, 6]. Egypt has to move from costly and resource-intensive wastewater treatment systems to more efficient and controllable ones. Reduce accidental organic matter, nitrogen, phosphorus, and nitrate pollution of groundwater and surface waters during this transition [6, 7]. These issues are prompting the development of novel, cost-effective physical-chemical wastewater treatment methods. The solutions should be simple to regulate, cheap to build and run, efficient, ecologically benign, and use little land and energy. Integrated and hybrid treatment techniques using many technologies are promising [7, 8]. Membrane separation, hydrogen peroxide-based oxidation, electrochemical oxidation, and sulphate radical-advanced oxidation may eliminate developing pollutants from recovered water and increase its safety [9]. Nanofiltration, ultrafiltration, and reverse osmosis are used for balancing water quality and energy usage [9]. Advanced physicochemical methods eliminate biological oxygen demand (BOD5), total nitrogen, and phosphates from municipal wastewater, making it appropriate for tree farming, fish breeding, and animal raising [10]. Compared to standard biological treatment plants, this method may recover a large amount of the energy consumed, saving money [11]. Electrocoagulation-electroflotation (ECF) technique treats and flocculates pollutants without coagulants [12]. Low installation and maintenance costs, minimum sludge generation, short settling periods, and excellent pollutant removal efficiency are achieved with this electrochemical wastewater treatment technology [13]. In ECF, two sets of anodes and cathodes are nearby, generating an electrocoagulation-flotation system. The cathode electrode releases metal ions into wastewater, which form hydroxide complexes to neutralize and agglomerate particulates. Due to hydrogen bubbles from the anode, these aggregated particles ascend to the tank surface for simple removal [14, 15].

Electrocoagulation-flotation reduces chemical coagulants, making treatment faster and less wasteful [16, 17]. It treats wastewater cheaply and sustainably. However, nanofiltration (NF) membranes with pore widths of approximately 1 nm are appropriate for drinking water, industrial wastewater treatment, and water reuse. NF membranes may hold dissolved salt ions and organic solutes without charge, making them a sustainable water treatment option [18]. NF membranes provide better permeation flow and lower pressures than reverse osmosis, saving energy [19]. This membrane may separate solutes or compounds from solutions, produce biomaterials, and work in the pharmaceutical business [20, 21]. As many developing nations struggle with water pollution, standard wastewater treatment systems are failing, particularly for new contaminants and heavy metals. Advanced physicochemical methods like nanofiltration and electrocoagulation-electroflotation may increase wastewater treatment, water quality, and environmental effects. These revolutionary devices may help reduce pollution and save water. More development and use of these sophisticated approaches are needed to fulfil global clean water demand.

Traditional methods, including biological, physical, and chemical methods, fall short of totally getting rid of household substances. One such treatment is electrocoagulation (EC), which uses aluminum anode and cathode electrodes to separate solids from liquids to separate treated sewage from active biomass. Therefore, the purpose of this study is to assess how well EC (electrocoagulation), followed by NF membrane, performs in the treatment of domestic sewage.

2. EXPERIMENTAL

2.1. Method: Research Design

This study comprehensively examines the treatment and reuse of municipal wastewater from our hospital from September 2022 to August 2023. To meet global water conservation and pollution goals, the main goal is to design a sustainable wastewater treatment technique. This research strategy begins with an organized collection of wastewater samples from the study region. After screening for solids, samples are treated in an Electrocoagulation-Nanofiltration (EC-NF) system.

Electrical coagulation and nanofiltration are possible with a storage tank, power sources, batteries, aluminium electrodes, and pipelines. The design optimizes operating duration and current density to evaluate the system's pollutant removal and water quality improvements. BOD, COD, TDS, color, pH, and anion/cation analysis are also used to assess treatment performance. The results from these studies will be carefully analyzed to see whether the EC-NF system meets treatment goals. Keep NF membranes intact with careful maintenance and cleaning practices. This study design intends to shed light on sustainable municipal wastewater treatment practices to improve water quality and resource management.

2.2. Inclusion and Exclusion

2.2.1. Inclusion

- Priority will be given to samples that have been screened for coarse solids and big contaminants, reflecting the real-world treatment procedure.
- The study uses an Electrocoagulation-Nanofiltration (EC-NF) wastewater treatment device.
- Water quality measures including BOD, COD, TDS, colour, pH, and anion/cation levels will be used to evaluate the EC-NF system.
- Data on the EC-NF system's ability to remove pollutants, improve water quality, and satisfy wastewater treatment goals will be prioritized.

2.3. Exclusion

- The study will only examine home wastewater characteristics, excluding industrial and non-domestic samples.
- The analysis will eliminate samples without prior screening to remove solid materials or significant pollutants since the emphasis is on treated wastewater.
- To concentrate on the EC-NF system, the research will not include data on alternative wastewater treatment systems.
- Data beyond BOD, COD, TDS, color, pH, and anion/cation values will be excluded.

2.4. Statistical analysis

This study uses descriptive statistics to summarize BOD, COD, TDS, color, pH, and anion/cation levels to reveal core patterns and data variability. Comparing pre- and post-treatment results will determine the Electrocoagulation-Nanofiltration (EC-NF) system's treatment efficacy using paired-sample t-tests or Wilcoxon signed-rank tests. Correlation analysis will also be done to see how the EC-NF treatment affects water quality. These statistical approaches assess the EC-NF system's efficiency and pollutant removal in municipal wastewater treatment.

3. RESULTS

Table 1 compares critical characteristics between EC-NF (Electrocoagulation-Nanofiltration) effluent and water reuse criteria, showing that the method is successful in treating wastewater for reuse. COD, BOD, and TSS in EC-NF effluent are considerably below water reuse limits. EC-NF effectively eliminates organic and suspended particles from wastewater, fulfilling water reuse criteria with BOD and COD levels of < 15 and ≤ 20, respectively. EC-NF effluent has stable turbidity and TDS levels, making it suitable for reuse. This comparison shows that EC-NF can treat water sustainably and effectively to fulfil reuse criteria.

Figure 1 shows the removal efficiencies of COD, BOD, NO3, and PO4 for three treatment methods: EC (Electrocoagulation), NF (Nanofiltration), and a combined EC-NF procedure at 12 hours HRT. COD and BOD removal efficiency is best with the combined EC-NF process, exceeding EC and NF independently. At 87%, EC-NF removes COD better than NF and EC alone at 75% and 66%, respectively. A similar tendency applies to BOD removal. The combined EC-NF method trails NF in NO3 and PO4 removal efficiency. This shows that EC and NF may be especially successful for organic pollutant removal, whereas NF specializes in nutrient removal, making it important to pick the right approach based on wastewater treatment objectives.

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

Figure 1: Efficiencies of HRT = 12 hours

PARAMETERS	CONCENTRATION (mg/L)	
Chemical Oxygen Demand	450-500	
Biological Oxygen Demand	160-200	
NO_3	4-5	
PO_4	5-6	
TSS	400-440	
PARAMETERS	EC-NF EFFLUENT	WATER REUSE
Biological Oxygen Demand	≤ 15	0-40
Chemical Oxygen Demand	≤ 20	0-100
Turbidity (NTU)	0	≤ 15
TSS (mg/L)	0	≤ 145
TDS (mg/L)	≤ 60	≤ 500
pH	≤ 8	6-8

Figure 2 depicts the influence of operating pressure (OP) on biological oxygen demand (BOD) removal % across different temperature settings in a wastewater treatment system. At an initial temperature of 25°C, when OP rises from 2 to 10 bar, there is a substantial drop in BOD removal percentage from 97.4% to 88%, demonstrating that greater pressure adversely impacts the efficiency of BOD removal. A similar pattern may be seen at 37°C when BOD removal declines from 88.5% to 86%. Interestingly, for various temperature and pressure combinations, the data is sparse, but the existing information implies a possible negative association between OP and BOD elimination. Further investigation is necessary to obtain a thorough grasp of this connection.

Based on the data in Table 4.2, the EC-NF and its permeate properties, such that we have COD, TSS, turbidity and TDS which is noteworthy, and the last BOD quantity, were found to be lower than the levels suggested for reusing water for irrigation in agriculture. It can be concluded from this finding that the combined NF and Nano filtration (NF) system worked amazingly well at cleaning up household waste so that it could be used again.

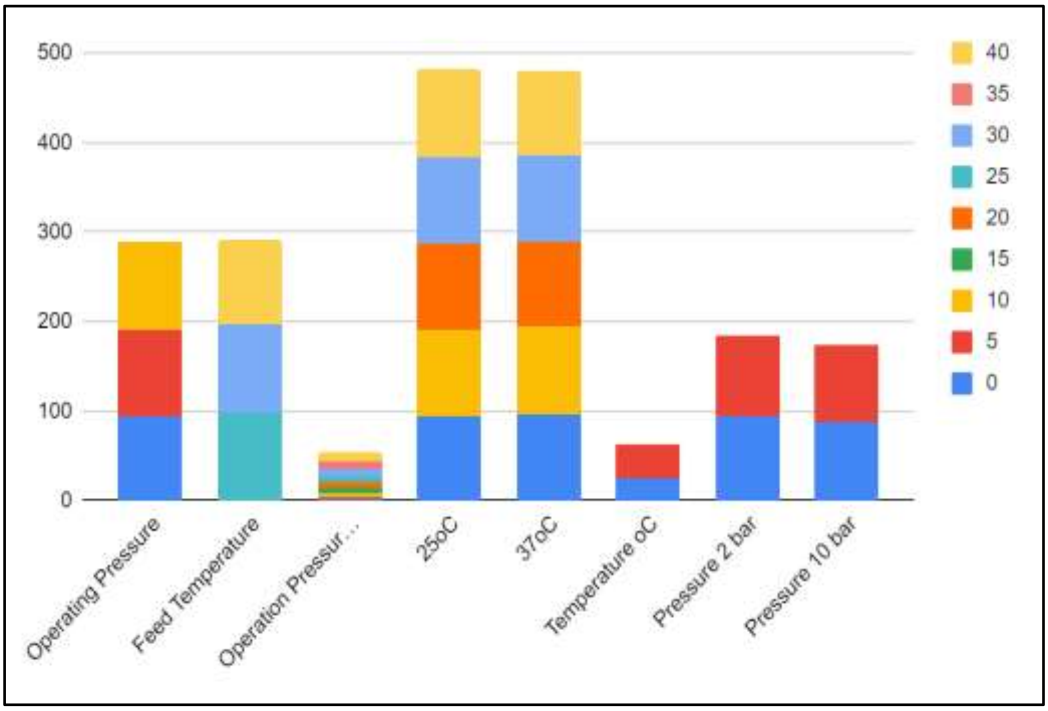

Figure 2: Impact of OP on BOD removal percentage

Electrocoagulation (EC) performance is assessed using objective responses and factors in Table 2. EC model coefficients (a0, a1) and correlation coefficient (R) show the intensity and direction of the variables' association. EC has favorable correlations and high R values for COD, BOD, NH3, TSS, and turbidity reduction, indicating efficient pollutant removal. The association coefficients for TDS and permeate flux are negative, suggesting the EC process may not affect these variables. The data also shows a modest positive association between HRT (Hydraulic Retention Time) and COD elimination. The regression analysis and model summary demonstrate that HRT affects COD elimination with a low p-value. The table shows how operational settings affect EC's pollutant removal.

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
Turbidity Removal	88.941	5.056	0.884
Permeate Flux	0.583	-0.208	-0.969
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.**	**N**				
COD Removal	84.4373	3.6242	15				
HRT	1.5	0.42258	15				
	Pearson Correlation						
COD Removal	1						
HRT	0.734						
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**			
1	0.734	0.538	0.503	2.55575			
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**		
Regression	98.973	1	98.973	15.152	0.002		
Residual	84.914	13	6.532				
Total	183.887	14					
Model	**Unstandardized Coefficients**	**Standardized Coefficients**	**B**	**Std. Error**	**Beta**	**t**	**Sig.**
1 (Constant)	74.999		29.847	2.513			0
HRT	6.292	0.734	3.893	0.002			0.002
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**N**		
Predicted Value	81.2913	87.5833	84.4373	2.65886	15		
Residual	-5.23733	4.40867	0	2.46278	15		
Std. Predicted Value	-1.183	1.183	0	1	15		
Std. Residual	-2.049	1.725	0	0.964	15		

Table 3 shows descriptive data and regression analysis for COD removal, pressure (bar), and temperature (°C). The dataset shows consistent performance with a mean COD removal of 97.181 and a minimal standard deviation. The mean pressure and temperature are 6 bar and 31°C. Pressure has a strong positive correlation (R = 0.992) with COD removal, while temperature has a negative correlation (R = -0.183), indicating that higher temperatures reduce COD removal efficiency. The coefficients and low p-values of the regression analysis show that Pressure has a positive and significant influence on COD Removal and Temperature has a negative and significant effect. These data explain the main parameters affecting COD elimination in this situation.

4. DISCUSSION

This tendency is due to rising current density. COD elimination efficiency increases with wastewater exposure length and current density. EC Biochemical Oxygen Demand (BOD) removal efficiency increases with longer exposure durations and greater current densities. The 5-minute removal rate averages 65.25%. Electrode corrosion during aluminum plate processing reduces removal efficiency somewhat [22].

Table 3: Descriptive Statistics

Variable	**Mean**	**Std.**					
COD Removal	97.181	1.49071	10				
Pressure (bar)	6	2.98142	10				
Temperature	31	6.32456	10				
Variable	**Pressure**	**Temperature**					
COD Removal	1	0.617					
Pressure		1					
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**			
1	0.992	0.985	0.98	0.2098			
Model	**Sum of**	**df**	**Mean**	**F**	**Sig.**		
Regression	19.692	2	9.846	223.698	0		
Residual	0.308	7	0.044				
Total	20	9					
Model	**Unstandardized Coefficients**	**Standardized Coefficients**	**B**	**Std. Error**	**Beta**	**t**	**Sig.**
1 (Constant)	101.008	0.376	268.33				0
Pressure	0.309	0.023	0.617	13.152	0		
Temperature	-0.183	0.011	-0.777	-16.565	0		

5 minutes of EC removes 15.2% of NO_3. Electrolysis duration increases removal efficiency. Electrolysis duration greatly affects EC efficiency, with 5 minutes producing 15.2%. Additionally, applied voltage and current density affect removal efficiency [23]. In comparison, Figure 4 shows the EC process's 93% PO_4 removal efficiency. Increased current density and electrolysis duration might accelerate metal dissolution by increasing PO_4 ion absorption. In 2005, researchers found that Al^{+3} and PO^{-3} precipitate $AlPO_4$ [24]. The EC system removes Total Suspended Solids (TSS) with 60% efficiency. Current density affects removal efficiency. Solids removal efficiency increases with current density. This research used five electrodes and 9.5 A/m2 current to remove 60% of suspended particles in five minutes [24]. The removal efficiency was maintained at 60% to maintain these results. Recycled water had limits, including high electrical conductivity

(EC) at 1350 µS/cm, high TDS levels (970 mg/l), and high BOD, COD, and ammonia NH_3 levels in household sewage, requiring extra treatment. High-quality reuse water was produced after NF treatment eliminated the remaining contaminants and organic substances. Operating pressure considerably affects NF COD elimination. Increased operating pressure improves wastewater membrane efficiency [25]. Due to increased membrane surface density, organic materials have lower permeability. Due to dissolved material concentration polarization at the membrane's surface, greater operating pressures increase osmotic pressure and COD removal efficiency. This creates a secondary barrier that blocks organic molecule transit across the membrane [26]. Increased feed temperature is bad for COD removal rates because it mechanically deforms membrane pores and increases pore size, allowing organic material to flow through. Despite temperature changes from 25 to 37°C, the NF membrane yields 94% to 99.4% clearance rates that fulfil reuse criteria [27]. Municipal wastewater with ammonia may harm the environment if not properly removed. Addressing this problem requires nanofiltration (NF) technology. Ammonia and other low-molecular-weight organic and inorganic salts are rejected efficiently by NF. For ammonia's low molecular weight components, NF membranes' capacity to reject organic molecules over 1 kDa is crucial. NH_3 removal efficiency is correlated with operating pressure. High operating pressure increases driving power and reduces membrane resistance, improving NH_3 removal. Previous research supports this association. Increasing feed temperature from 25 to 37°C reduces NH_3 removal efficiency. NF membranes remove NH_3 from wastewater at appropriate rates [28]. Although BOD removal efficacy decreases with temperature, the membrane effectively eliminates BOD from home sewage samples. The particle size distribution in wastewater samples, where BOD particles are bigger than membrane pores, explains this efficiency. NF membranes can effectively reduce TDS levels in domestic sewage effluent to fulfil reuse criteria, making their usage essential. Operating pressure increases TDS removal rates [29]. Higher working pressure reduces membrane resistance and compaction, improving TDS removal efficiency. In contrast, raising feed temperature decreases efficiency and TDS removal rates. NF membranes regularly remove TDS at sufficient rates, making them suitable for wastewater reclamation and reuse. The results show that EC and NF methods remove contaminants from wastewater [30]. EC removes COD, BOD, NO_3, PO_4, and TSS at different rates depending on exposure period, current density, and electrode corrosion. Operating pressure and feed temperature affect COD, NH_3, BOD, and TDS removal rates in the NF process. These results show that EC and NF technologies can clean and reuse wastewater sustainably.

5. CONCLUSION

This research's experiments on Nano Filtration (NF) devices for domestic wastewater treatment and reuse have major ramifications. The NF system removes a variety of impurities from actual residential sewage with astonishing efficiency. Total Suspended Solids (TSS) removal reached 99.6% and Chemical Oxygen Demand (COD) reduction was 91.6%. It worked well under a 2-day Hydraulic Retention Time (HRT), indicating its practicality. The study also shows that operational parameters including HRT, mixed liquid suspended solids (MLSS), and clearance rates are correlated, highlighting their importance in improving removal efficiency. Integrating the NF system with a pilot-scale system seemed to achieve optimal residual pollutant removal rates for safe reuse. Notably, the linear correlations between operating pressure and elimination rates and feeding temperature and permeate flow help optimise NF systems. These results help us understand how operational parameters affect NF treatment and reutilization of household wastewater and emphasize the significance of optimizing these aspects to reach desired removal efficiencies and permeate flow rates.

6- RECOMMENDATIONS

Drawing from the findings of the present inquiry, the ensuing recommendations are proposed:

1. Examine if the EC-NF system is appropriate for handling different kinds of wastewater, such as synthetic, car wash, and industrial wastewater.

2. Employ different electrocoagulation and NF operation parameters, like different electrolysis durations and concentrations.

3. Even though the NF membrane was assessed in this work, it is suggested that a different membrane be looked at, such as the microfiltration MF membrane.

4. Examine if an EC-RO system is appropriate for treating sewage or municipal wastewater.

It is imperative to do an economic feasibility analysis to ascertain the practicality of treating municipal wastewater through this approach.

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