AIMS Environmental Science

AIMS Environmental Science, 11(1): 57–74.
DOI: 10.3934/environsci.2024004
Received: 30 October 2023
Revised: 20 December 2023
Accepted: 24 January 2024
Published: 05 February 2024

http://www.aimspress.com/journal/environmental

*Research article*

# Treatment of greywater by Electrocoagulation process coupled with sand bed filter and activated carbon adsorption process in continuous mode

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**Abstract:** Worldwide population growth and consumerism have elevated the water pollution problem to the top of the environmental priority list, with severe consequences for public health, particularly in agricultural countries such as India, where water scarcity is a big challenge. Hence, greywater has the potential to be one of the most sustainable options to meet the growing need for freshwater with satisfying treatment options. This study focused on the assessment of electrocoagulation coupled with the filtration and adsorption processes in continuous modes and different electrode arrangements including (Al-Fe-Al-Fe), (Fe-Al-Fe-Al), (Al-Al-Al-Al) and (Fe-Fe-Fe-Fe) to investigate the effect of specific flow rates (i.e., 0.05 and 0.1 liters per minute) on the removal efficiency. The findings show

that a 0.05 lit/min flow rate produces a higher removal efficiency approximately between 85 to 90% with an energy consumption of between 0.5 to 4.75 KWh/$m^3$ as compared to the 75 to 85% removal efficiency and 0.4 to 4 KWh/$m^3$ energy consumption at a flow rate of 0.1 lit/min. The operational cost is variable and mainly depends upon the energy consumption; moreover, it was found that the optimal results and economy variation shown by the electrode assembly of Al-Fe-Al-Fe was between 20 to 22 Indian rupees at a 24 volt current density and in each combination of electrodes.

**Keywords:** electrocoagulation process; sand bed filter; activated carbon; continuous mode; greywater

## 1. Introduction

The need for clean water has increased due to population growth [1] and economic development [2], thus leading to a disparity between available water sources. To address this, decision-makers need to view treated wastewater as an asset [3] rather than as waste for disposal. Greywater (GW), which includes wastewater from various sources except for toilets [4], is being recognized as a resource for reclamation and reuse projects [5]. Greywater consists of accumulated wastewater from bathrooms, wash basins, clothes washers, and kitchen use but excludes toilet streams. Greywater is divided into pale greywater and dark greywater categories [6]. Soaps, cleansers, body grooming products, tresses, body lipids, cloth fibers, etc., are found in bathroom water and are partitioned in the category of light greywater; alternatively, dark greywater has more contaminants from laundry facilities, dishwashers, kitchen sinks, etc., [7]. According to the survey, approximately 27% of greywater originates from the kitchen sink and dishwasher, 47% from the washbasin, bathroom, and shower, and 26% from the laundry and the washing machine [8]. Greywater and black water characteristics are strongly influenced by residents' lifestyles, social and cultural practices, as well as the availability and usage of water. Domestic greywater contains substantial organic matter, primarily from using soap or soap-based products during bathing. The quality of greywater may vary due to various factors, including its source and geography, demographic characteristics, and population density, among other determinants. In several kinds of greywater, a reduction in suspended particles and turbidity indicates a raised presence of contaminants in a dissolved state. However, an effective treatment is crucial for safe and sustainable reuse [9]. The spectrum of greywater remediation technologies is vast in diversity and efficacy [10]. Numerous studies have investigated various methods for treating this form of water. Due to its relatively low concentration of hazardous microorganisms [11] and nitrogen content [10,12], the reuse and recycling of greywater has become increasingly feasible. Recognizing its potential, efforts are being made to improve greywater treatment procedures to satisfy the necessary criteria for quality standards across a range of applications, including irrigation [3] and other non-potable uses [12]. Greywater remediation is an amalgamation of physical, chemical, and biological processes, as evidenced by various sources [13,14]. Physical and chemical techniques are commonly efficacious in removing suspended solids, organic matter, and detergents. However, their financial feasibility may be limited in addressing dissolved constituents [14]. The utilization of physical processes during isolation may prove inadequate in mitigating the presence of dissolved organic or inorganic pollutants. Implementing a synergistic approach that integrates an aerobic biological process with either physical or physicochemical techniques, in conjunction with advanced electrochemical methods such as electrocoagulation (EC), is effective in treating greywater, as

evidenced by previous studies [15] and highlighted in Figure 1. Electrocoagulation is a sophisticated electrochemical technique used to purify water, in which electricity [16] plays a crucial role in eliminating impurities from water sources [16]. This technique has been extensively investigated and implemented in numerous contexts. According to Kobya et al. [17], the method employs an electrical current to destabilize and aggregate particulate matter, colloidal particles, and solute substances. To counteract the effects of electrostatically charged particles, metal ions released by self-sacrificing electrodes can function as coagulating agents. As stated in the cited source [16], the resulting floc conglomeration can be readily separated using techniques such as sedimentation and flotation.

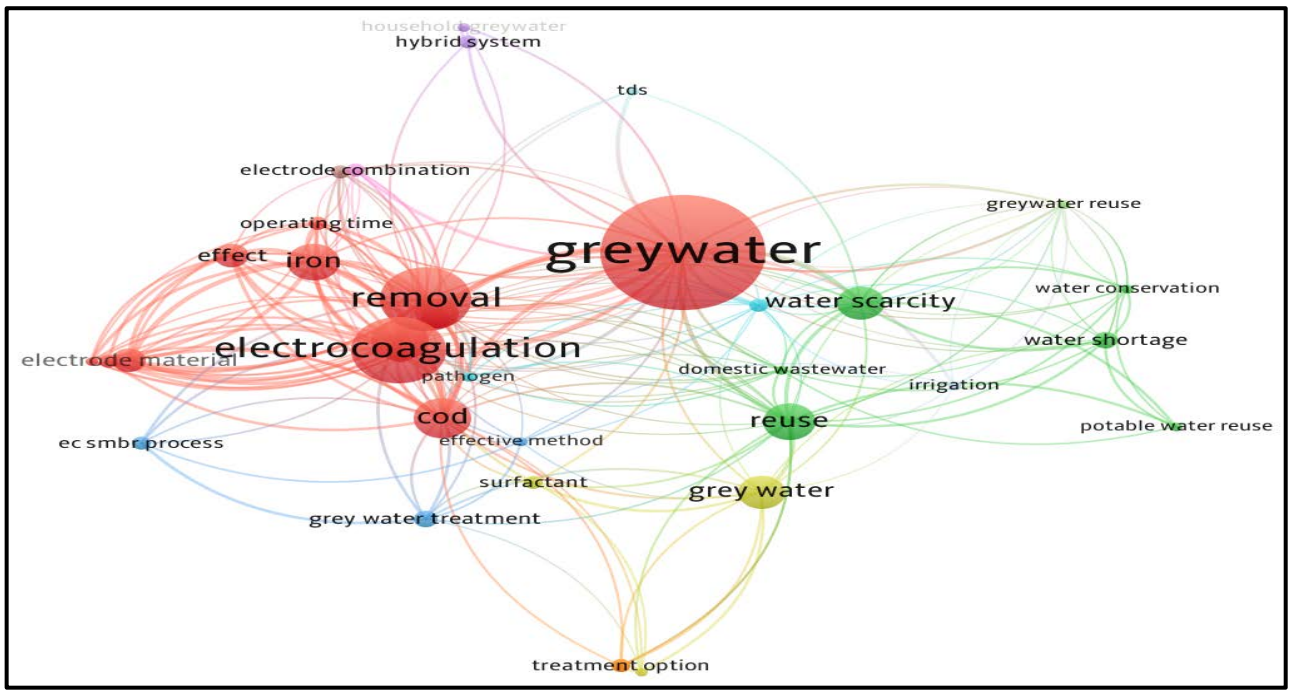



**Figure 1.** Network Analysis of Greywater with Electrocoagulation System study from year 2003 to 2022.

Batch-scale EC processes have a more significant impact and have been extensively studied by researchers [18–21]. Some of the critical factors widely evaluated in water and wastewater treatment include initial pollutant concentration, pH levels, the magnitude of applied electrical voltage or power, the time frame of treatment and conditions of temperature, the distance between electrodes, rotating velocity, the spatial separation of electrodes, and the presence of support electrolytes. There are a few hurdles to overcome before this technology can be implemented, such as analyzing the extraction of contaminants in a continuous process, ascertaining which factors significantly impact the removal effectiveness and the ability to maintain an effective operating system. Additionally, researchers have been looking into removal processes and the subsequent operational parts for more than three decades. As a result, some researchers have decided to test the method in batches and utilize continuous processing [20,22–31].

The prime objective of this work is to present a continuous treatment of greywater by an electrocoagulation filtration process with an optimal flow rate performed at different electrode combinations, to evaluate its efficiency and operational cost regarding the operating time.

## 2. Materials and methods

### *2.1. A Compilation of greywater samples*

Influences GW samples were taken from 10 different families in Nagpur, India, with an average of 6 active people; a sampling approach was employed to collect the samples, which was referred to as the sampling procedure mentioned in APHA, 2005. The water originating from the bathrooms, wash basins, clothes washers, and kitchen sources were blended and composited into a plastic container. The samples were stored at $4^0$ Celsius until they could be examined more thoroughly. The characteristics of the influents in the samples are shown in Table 1.

**Table 1.** Characteristics feed process, No: 10 samples, SD: Standard Deviation.

| Factors | Least | Most | Average | SD |
|---|---|---|---|---|
| pH | 6.6 | 8.4 | 7.3 | 1.5 |
| Turbidity (NTU) | 30 | 90 | 46 | 14.5 |
| TDS (mg/lit) | 180 | 350 | 239 | 105 |
| TSS (mg/lit) | 35 | 190 | 80 | 45 |
| COD (mg/lit) | 130 | 430 | 245 | 170 |
| Chloride (mg/lit) | 15 | 55 | 24.5 | 10.3 |
| Sulphate (mg/lit) | 29 | 68 | 35 | 11.5 |

The flow rate of water calculated by Q (discharge) = v (volume) / t (time)

### *2.2. Experimental setup*

The experimental setup at the laboratory scale involved an electrocoagulation reactor, which was subsequently compiled with a sand-bedding filtration system. The employed activated carbon adsorption process (ECF) was made of acrylic materials with dimensions of [24 cm (H) x 20 cm (L) x 10 cm (W)], a volume of 5 liters, and a thickness of 0.4 cm. The reactor had an arrangement of a V notch provided at 17 cm from the bottom for effluents to transform to another compartment with an inlet and an opening of 1 cm diameter. The V notch was provided for the slow discharge of effluents so that the maximum sludge produced would be manually removed by the separator, as shown in Figure 2 for the experimental setup.

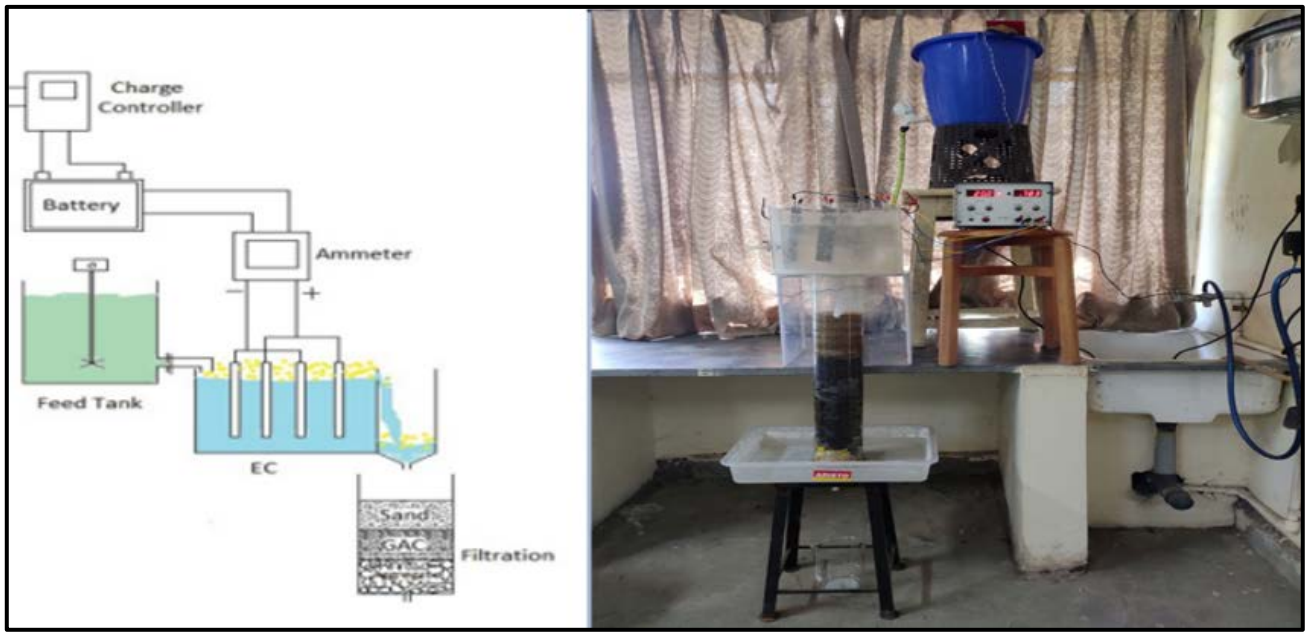



**Figure 2.** Experimental setup.

*2.3. Electrode materials*

The type of electrode material that is utilized is crucial because it determines the type of reaction that will occur, and hence, based on the researcher's experience, aluminum and iron are the most used electrodes due to their demonstrated durability and availability; however, iron (Fe) and aluminium (Al) show excellent performances in destabilizing colloid particles as compared to other materials. Therefore, the electrodes used in the present study were aluminium and iron, with an affective dimension of 18.5 cm (H) x 5 cm (W) x 0.02 (thickness), thus covering a total surface area of 92.5 $m^2$. The distance of the electrode was maintained 4 cm apart with four nos. of the electrode in anode-cathode combinations. The anode and cathode's importance are crucial for the electrode to function with the reaction, as shown in Table 2.

**Table 2.** The cathodic and anodic reactions occur for aluminium (Al) and iron (Fe) electrodes.

| | |
|---|---|
| Aluminium electrode | |
| Anode | $Al \rightarrow Al^{3+}_{(aq)} + 3e^-$ |
| In the solution | $Al_{(aq)}^{3+} + nH_2O \rightarrow Al(OH)_n^{(3-n)+} + nH^+$ ($n$=1,2,3…) |
| Cathode | $nAl(OH)^n \rightarrow Al_n(OH)_{3n}$ |
| Iron electrode | |
| Anode | $Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^-$ |
| In the solution | $Fe^{2+}_{(aq)} + nH_2O \rightarrow Fe(OH)_n^{(2-n)+} + nH^+$ ($n$=1,2,3…) |
| Cathode | $2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)}$ |

*2.4. Preparation of filter media*

After treatment from the EC process, GW effluent was purified using a gravity-controlled

technique that relied on natural strata such as sand, gravel, and activated carbon to seize the color, odor, suspended solids, and organic pollutants. The filtration media utilized in the experimental setup consisted of a Plexiglass measuring 60 cm in height and 10 cm in diameter. This media had a centrally located aperture of 1.5 cm at the bottom. The activated carbon was made from coconut shells ranging from 0.2~0.8 mm, fine sand ranging from <0.5 mm, and a gravel support with an effective size of 4.75 mm was utilized in the experiments after being thoroughly sieved, washed, and dried at $105^0$ Celsius. The distribution of each material was kept consistent by providing a small mesh at intervals (15 cm fine sand, 15 cm activated carbon, 15 cm gravel, 5 cm pebbles) and a 10 cm freeboard at the top. The investigations were conducted at room temperature, with continuous monitoring of the final effluents at every 0 to 60minute operational intervals of 10 minutes. After completing each ECF experiment, the EC reactors and filters underwent a backwashing process.

### *2.5. Analytical studies*

Samples were collected, and the properties were analyzed from both incoming and outgoing streams to investigate the physiochemical treatment of GW using a combination of floatation with a sand filtration process. The feed samples underwent analyses for various water quality parameters, including chemical oxygen demand (COD), using cuvette tests conducted with a Hach UV vis Spectrophotometer (Hach, DR 2000) at the wavelength of 620 nm with the provision of COD digestor (Hach DRB 200), total suspended solids (TSS) and total dissolved solids (TDS) with a(Hach, DR 2000), pH with digital meter and the provision of temperature Type 362, and turbidity with a µ controller-based turbidity meter Type 135; chloride and sulfate ions were analyzed following the protocols specified in the standard methods [APHA 2005]. After each experimental run, the electrodes were washed properly with a solution of 2N HCl to remove organic contaminants.

### *2.6. Experimental procedure*

The EC experimental set-up was carried out in a continuous mode, thereby varying the current voltage from 6 to 24 volts to maintain a detention duration of 45-60 minutes, as shown in the systematic flowchart in Figure 3. After the EC process, the GW effluents were passed to a second tank, which had a 10 mm orifice at the lowermost point. Effluents passed through the orifice and were transferred into a filtering unit.

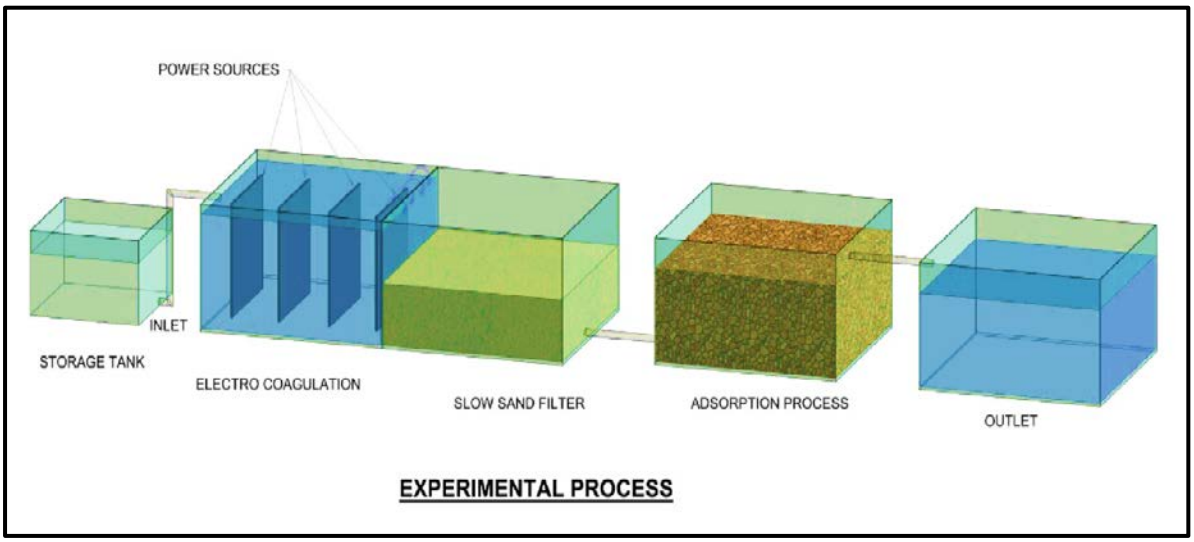


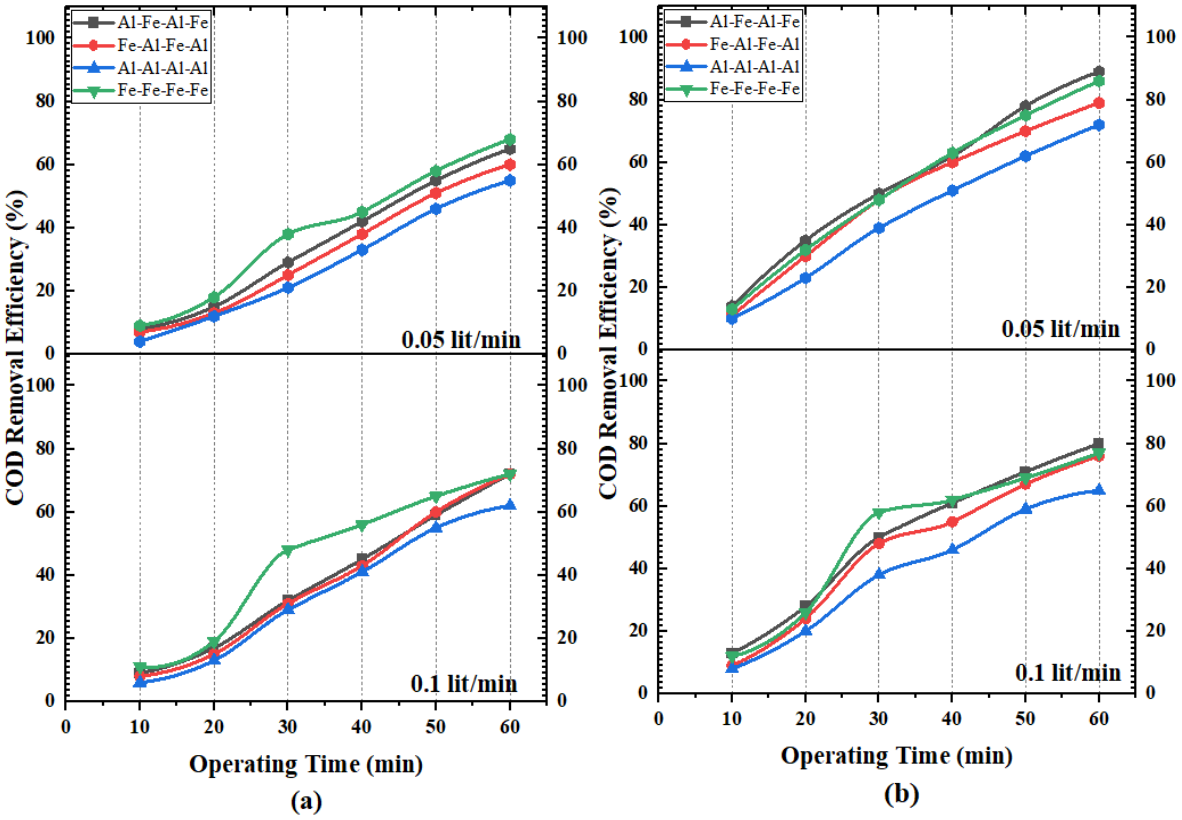

**Figure 3.** Experimental setup flowcharts.

## 3. Results and discussion

### *3.1. Effect of flow rate and voltage*

The electrode current flux (voltage) and inlet flow rates are crucial for the operational performance of a continuous EC system. ECF experiments were carried out with different current-voltages (i.e., between 6 to 24 V), and detention times were conducted to study the effects of turbidity, COD, and TDS removal efficacy for different flow rates, as shown in Figures 4 and 5. According to a study, the removal efficacy of an EC interaction is affected by the flow rate (Q) to the reactor. Reducing the flow rate increased the hydraulic detention time in the EC reactor, thus re-establishing metal hydroxide flocks and improving removal processes. This experiment showed the COD elimination effectiveness at a flow rate of 0.05 lit/min for the electrode combination Al-Fe-Al-Fe (77.6%,85.12%,88.53%,) and 0.1 lit/min (76.59%, 80.75%,84.5%) for 6, 12, and 24 volts, respectively, which were caused due to a decrease in $Al(OH)_3$ production. This resulted from hydraulic detention, which led to an increase in the dissolution rate of $Al^{3+,}$ which subsequently enhanced the formation of $Al(OH)_3$ and the liberation of $H_{2(gas)}$, consequently reducing the size of the bubble diameter [20]. Additionally, it was noticed that the extent of removal from the electrode combination of Fe-Fe-Fe-Fe showed a good efficiency of almost 88% reduction by the 24 V applied voltage solely due to the formation of $Fe^{2+}$ during the electrochemical process developing at both the anode and cathode, which possessed a higher oxidation. In terms of the removal efficiency, the results belonging to the Fe-Al-Fe-Al combination were pretty similar to the Fe-Fe-Fe-Fe combination [4], with a common reaction occurring at the cathode [$2H_2O_{(l)} + 2e^- \rightarrow H_2(g) + 2OH^-_{(aq),}$], which ultimately generated hydroxide ions and hydrogen gas. Curiously, research has also demonstrated that utilizing aluminium as a cathode can induce a dissolution phenomenon that defies the limitations of conventional electrochemical processes, which exclusively accounts for the dissolution of anodes. The most likely cause is a chemical attack on the aluminium cathode caused by hydroxyl ions generated during water reduction. This suggests that the observed dissolution at the aluminium cathode is attributed to a chemical reduction process in an electrochemical

reaction that typically occurs at the cathode [1,23,32,33].



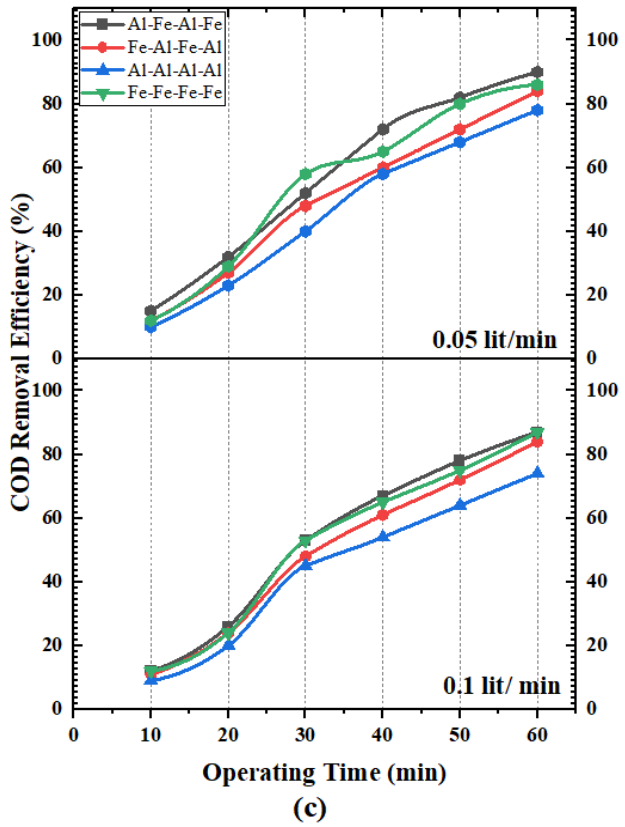



**Figure 4.** Effect of COD removal efficiency by Electrode configuration at a flow rate of 0.05 lit/min and 0.1 lit/min for current (a) 6V, (b) 12 V and (c) 24 V.

The total electrical current detected in the cathodic potential range generally arises from the concurrent reduction of oxygen and water at a surface and the rate of aluminium oxidation. The variation of this surface activity is contingent upon the applied voltage [33]. At the same time, consideration of the Al-Al-Al-Al combination was found to be weak in the COD removal efficiencies and almost covered with a flow rate of 0.05 lit/min (56.36%, 76 %, 79%) for 6, 12, and 24 volts, respectively, which may be due to a low level of metal hydroxides that developed during the experimental investigation. The effect of the flow rate is crucial, as it increases in the ECF reactor. The retention duration displayed a decrease and allowed the coagulant generated by the electrochemically dissolved electrodes to be appropriately integrated with the pollutants in the wastewater to ensure proper mixing, thereby improving the coagulation rate. For parameters such as turbidity, TSS, TDS, and number of chloride ions, there was a profound change in the removal effectiveness between (0.05 and 0.1) lit/min. This may be because of an elevated flow rate of the GW suspension, which subsequently decreased in working duration and current potential. In both cases, increasing the voltage electrode dissolution of Al-Fe-Al-Fe combination anodes made it feasible to generate polymeric metallic compounds and Al-Fe hydroxide, which improved the EC reactor's efficacy in removing the turbidity, TDS, and chloride ions.

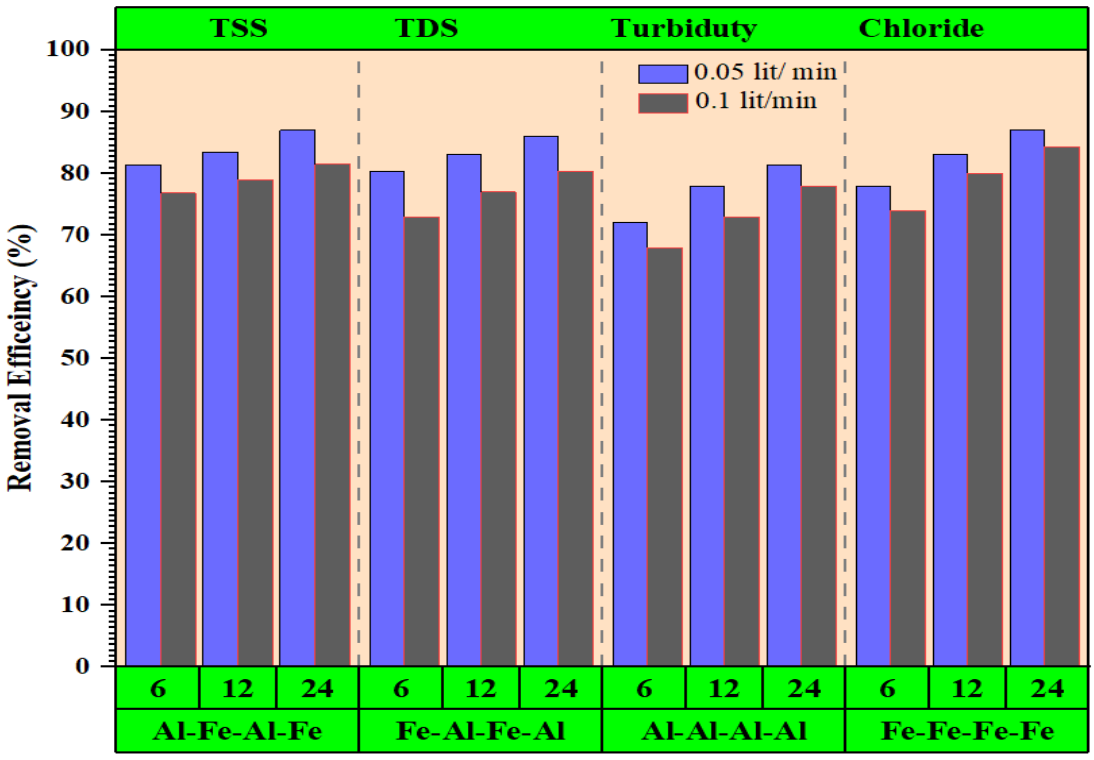
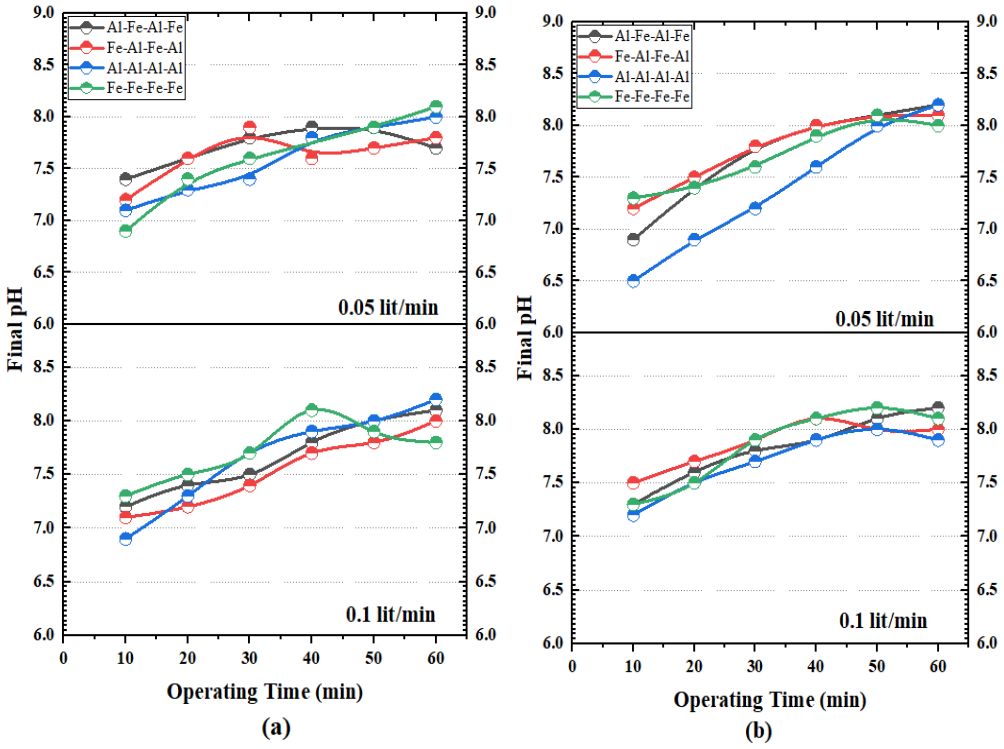



**Figure 5.** Effect of TSS, TDS, Turbidity, and Chloride removal efficiency by Electrode assembly at a flow rate of 0.05 lit/min and 0.1 lit/min for current 6V, 12 V, and 24 V.

For the chloride concentrations for the best electrode combination (Al–Fe–Al–Fe) , the number of anions dramatically reduced with time, as seen in Figure 5. The chloride ions reacted with the OH ions in the medium to produce Fe $(OH)_3$ and NaCl, which then combined to create $FeCl^3$.

### *3.2. Effect of pH*

pH is a crucial factor in the continuous flow EC process because it affects the electrical conductance of the solution, and erosion of the electrodes is critical to achieve high removal efficiencies. Based on the results shown in Figure 6, the optimal conditions with the highest COD and other characteristics of GW concerning flow rates of 0.05 lit/min and 0.1 lit/min for all electrode combinations (Al–Fe–Al–Fe), (Fe-Fe-Fe-Fe), (Fe-Al-Fe-Al) and (Al-Al-Al-Al) increased the determination of the removal efficiency, which was conducted within the pH range of 7.3 to 8.0. This can be attributed to the rapid development of gaseous hydrogen at the cathode, which increased the concentration of hydroxyl ions such as $Al(OH)_2$ and $Al(OH)_3$. At the same time, Fe (II), Fe (III), $Fe(OH)_3$, and oxidation elicited flavors within the solution. These electrochemical processes ultimately resulted in a high concentration of hydroxyl ions, and the pH showed decreasing trends in the flow rate of 0.1 lit/min due to hydrolysis and electrode oxidation $(OH)^{4-}$ at the anode, as well as in the cathode electrons, which were produced and immediately consumed by $H_2$ (g) evolution, this leading to an increase in the pH [34].



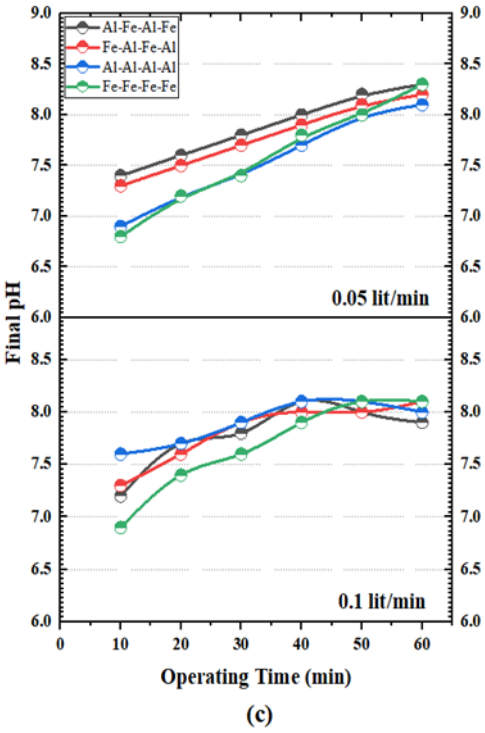



**Figure 6.** Effect of Final pH changes by electrode arrangements about the flow rate of 0.05 lit/min and 0.1 lit/min for current (a) 6V, (b) 12 V and (c) 24 V.

### *3.3. Energy consumption*

The most critical measurement for the EC process in a continuous mode is the energy consumption required to treat the GW, as shown in Figure 7. The removal efficiency of contaminants improved as the current-voltage and detention time increased from 45 to 60 minutes. The effectiveness with which contaminants of GW are removed is directly connected to the amount of metal ions on the electrodes. As the electrolysis time increases, the concentrations of metal ions and their attendant presence of hydroxide flocs increases, which, in turn, highlights anodic electrolysis, thus resulting in the formation of coagulation products. As illustrated in Figure 7, ECF treatment of GW is reported to consume less energy at 0.05 lit/min compared to 0.1 lit/min, while still removing a negligible quantity of COD (>92 %) in all electrode combinations. Again, additional consumption of specific energy (3.2~3.4) was observed in the variety of 4 (Fe) electrode combinations and less (2.3~2.6) in a combination of 2 (Al-Fe) in both cases. Thus, the amount of specific energy consumed increases as the voltage in the electrochemical cell increases, necessitating an increase in aluminium dosage released into the solution, which may be due to the rise in the conductivity of the GW suspension and an increase in the working duration and current potential. The production of removal efficiencies was slightly higher at 0.1 lit/min than at 0.05 lit/min, which may be attributed to colloidal contaminants being destabilized during the production [16,35]. In both cases, increasing the electrode dissolution of the Al-Fe-Al-Fe combination anodes made it feasible to generate polymeric metallic compounds and Al-Fe hydroxide, which improved the EC reactor's efficacy in removing COD, turbidity, TDS, and chloride ions.

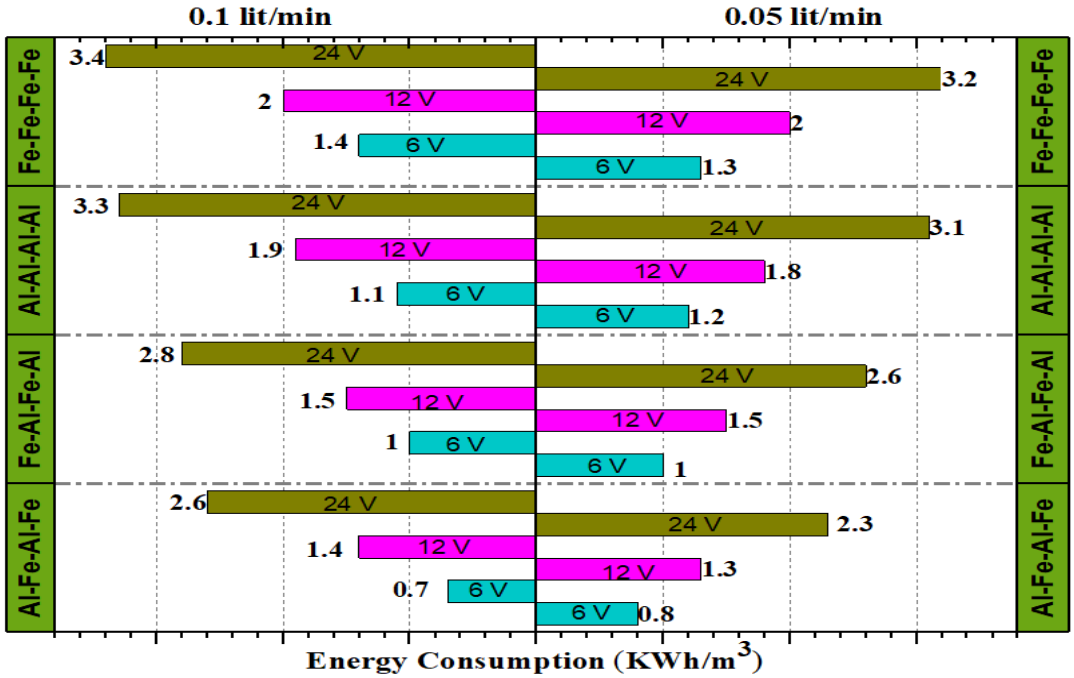



**Figure 7.** Effect of Final Energy Consumption at a different flow rate.

### *3.4. Operational Cost Estimation*

According to the findings of various researchers, the efficacy of the EC filtering method is impacted by the financial expenses associated with the treatment procedures. This aspect poses a significant drawback, especially when considering its application in enormous-scale industrial settings [1,4]. Notwithstanding this fact, the technology has garnered limited attention, as evidenced by the scarcity of published studies concerning the examination of operational expenses. The operating rate (OPc) in the ECF process encompasses the consumption of electrical energy, the cost associated with electrode consumption, the expenses related to the management of sludge disposal on landfills, the utilization of filtration mediums, and any additional fixed expenses. These costs are estimated to average Indian Rupees (INR) 1.1 kg/$m^3$. The operating cost is determined by considering the expenses associated with electrical energy, electrode material, and maintenance. This calculation is expressed in Table 3 through the equations below [4,21].

$$OPc = Cost\ Energy + Cost\ Electrode + Cost\ Maintenance \quad (1)$$

$$Cost\ of\ energy\ (kWh/m^3) = \{(Cv*i_0*t_o) / Vol\} \quad (2)$$

$$Cost\ of\ Electrode,\ (kg/m^3) = \{(i_0*t_o*M) / (Z*Fc*Vol\} \quad (3)$$

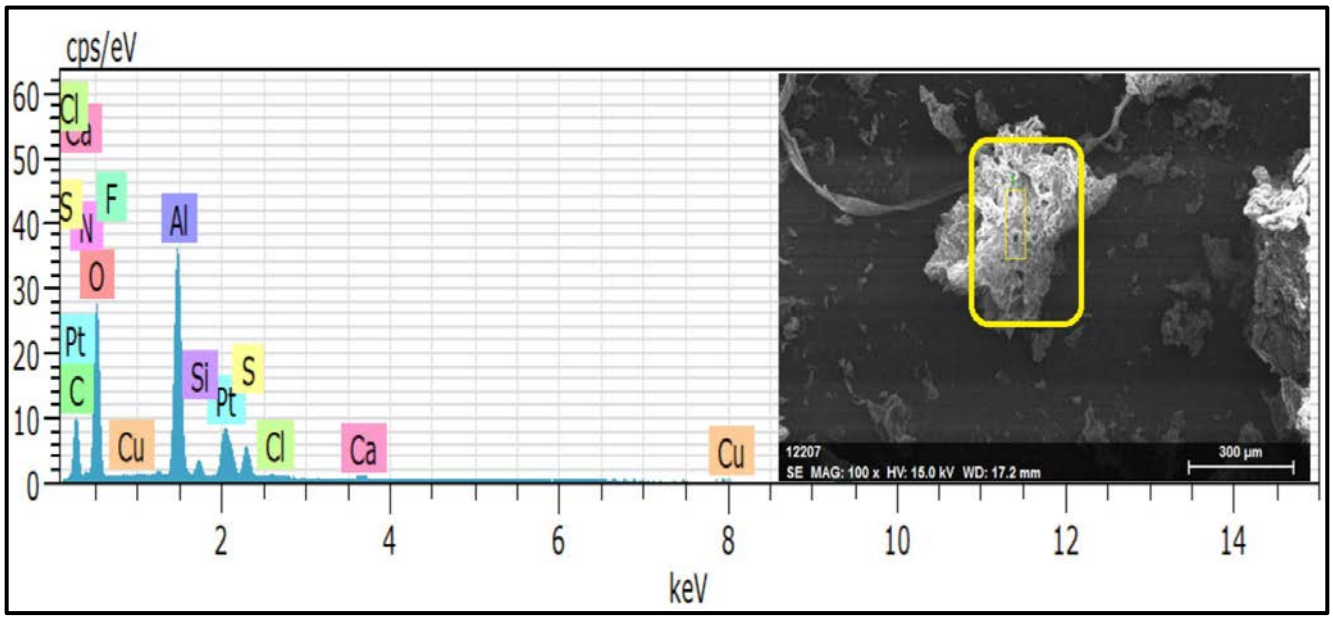
**Table 3.** A study of different electrode materials for the continuous mode treatment of greywater.

| EC+ Filtration | Mode | Cv (V) | CD (A) | $C_{energy}$ $_{KWh/m^3}$ | $C_{electode}$ $_{kg\ Al/m^3}$ $_{kg\ Fe/m^3}$ | | $C_{Main}$ (INR) $_{kg/m^3}$ | $OP_c$ in INR/$m^3$ |
|---|---|---|---|---|---|---|---|---|
| Al-Fe-Al-Fe | 0.05 | 6 | 0.45 | 0.5625 | 0.009 | 0.027 | 1.1 | 6.60 |
| | lit/min | 12 | 0.72 | 1.8 | 0.014 | 0.043 | 1.1 | 12.15 |
| | | 24 | 0.95 | 4.75 | 0.018 | 0.057 | 1.1 | 21.62 |
| Fe-Al-Fe-Al | | 6 | 0.48 | 0.6 | 0.009 | 0.029 | 1.1 | 6.97 |
| | | 12 | 0.83 | 2.075 | 0.016 | 0.050 | 1.1 | 13.84 |
| | | 24 | 1.23 | 6.15 | 0.024 | 0.074 | 1.1 | 27.66 |
| Al-Al-Al-Al | | 6 | 0.45 | 0.5625 | 0.009 | 0.027 | 1.1 | 6.60 |
| | | 12 | 0.8 | 2.25 | 0.017 | 0.054 | 1.1 | 14.91 |
| | | 24 | 1.0 | 5 | 0.019 | 0.060 | 1.1 | 22.70 |
| Fe-Fe-Fe-Fe | | 6 | 0.6 | 0.75 | 0.012 | 0.036 | 1.1 | 8.43 |
| | | 12 | 0.98 | 2.45 | 0.019 | 0.059 | 1.1 | 16.14 |
| | | 24 | 1.35 | 6.75 | 0.026 | 0.081 | 1.1 | 30.25 |
| Al-Fe-Al-Fe | 0.1 lit/min | 6 | 0.35 | 0.4 | 0.007 | 0.021 | 1.1 | 5.38 |
| | | 12 | 0.65 | 1.6 | 0.013 | 0.039 | 1.1 | 11.07 |
| | | 24 | 0.9 | 4.5 | 0.017 | 0.054 | 1.1 | 20.54 |
| Fe-Al-Fe-Al | | 6 | 0.5 | 0.6 | 0.010 | 0.030 | 1.1 | 7.21 |
| | | 12 | 0.89 | 2.2 | 0.017 | 0.054 | 1.1 | 14.76 |
| | | 24 | 1.3 | 6.5 | 0.025 | 0.078 | 1.1 | 29.17 |
| Al-Al-Al-Al | | 6 | 0.4 | 0.5 | 0.008 | 0.024 | 1.1 | 5.99 |
| | | 12 | 0.85 | 2.1 | 0.017 | 0.051 | 1.1 | 14.14 |
| | | 24 | 1.1 | 5.5 | 0.021 | 0.066 | 1.1 | 24.86 |
| Fe-Fe-Fe-Fe | | 6 | 0.7 | 0.9 | 0.014 | 0.042 | 1.1 | 9.65 |
| | | 12 | 1 | 2.5 | 0.019 | 0.060 | 1.1 | 16.45 |
| | | 24 | 1.4 | 7.0 | 0.027 | 0.084 | 1.1 | 31.33 |

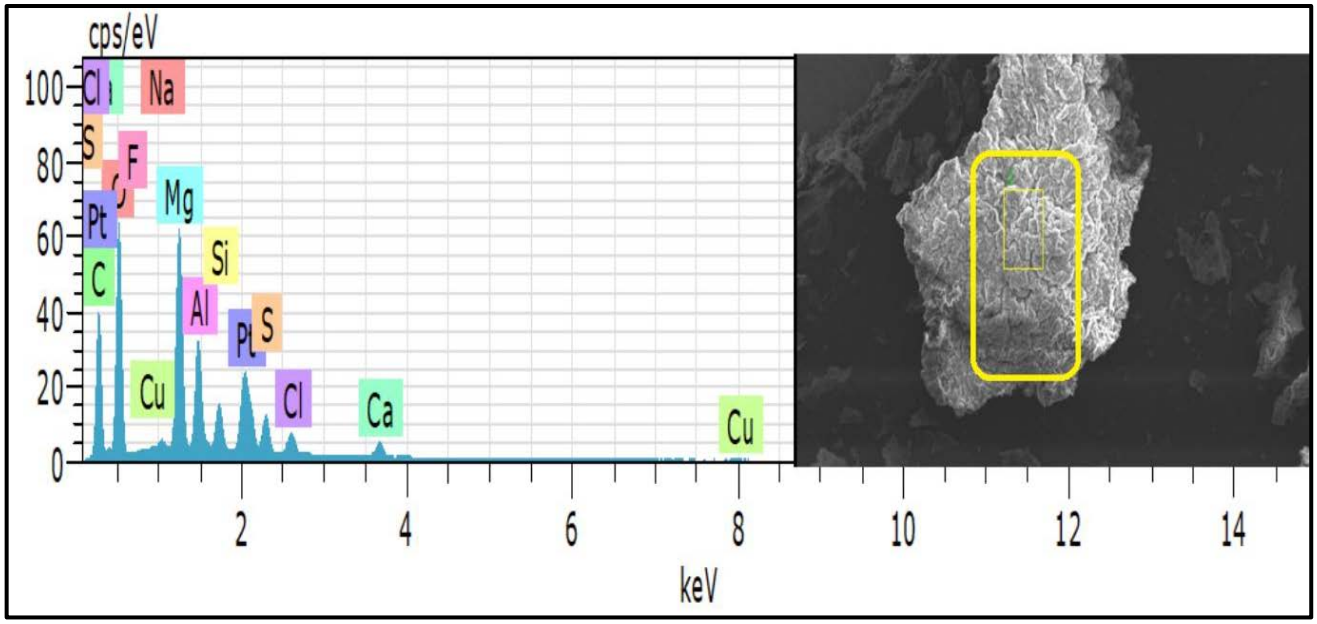
Where, Cv= cell voltages (V); $i_0$= current (Amp); $t_o$= operating time (hrs); Vol=wetted volume of the reactor ($m^3$); M=molecular wt. of Fe/Al (g/mol); Z=amount of electrons involved in the EC process (2 for Fe and 3 for Al); Fc=faradays constant (96485 C/mol); CD= current density (A), Electrical consumption unit pricing for the Nagpur area was set at Indian Rupees (INR) 3.7/kWh, while the price of electrode material was set at INR 40/kg for Fe and 110/kg for Al.

The cost parameter of the EC filtration process highlights the investigation on energy and electrode consumption for the Al-Fe-Al-Fe assembly based on the experimental investigation observations shown in the above Table 3.

*3.5. Sludge Characterization by SEM and EDS Analysis*




**(a)**




**(b)**

**Figure 8.** SEM and EDX analysis for Al-Fe-Al-Fe electrode arrangement at different flow (a) 0.05 lit/min and (b) 0.1 lit/min.

Microstructurally, sediment characterization is crucial for the recovery of GW and the reduction of pollution. This procedure involves examining functional groups with scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX). As depicted in Figure 8a,b, these techniques

are utilized after subjecting the sludge to an EC treatment process at 24 Volts and a flow rate of either 0.05 lit/min or 0.1 lit/min for the Al-Fe-Al-Fe electrode assembly. During the treatment process, the sediment generated under various voltage distribution conditions exhibited a significant degree of particle agglomeration, according to the experimental findings.

In addition, the energy-dispersive X-ray (EDX) spectroscopy analysis revealed the presence of multiple elements and their atomic intensities.

### *3.6. Comparative Results with Other Studies (Performance and Cost)*

In the treatment of GW, only a few studies have been performed to evaluate the efficacy of EC and filtration. After carrying out the investigation, it was discovered that the EC filtration process covered in the current study performed much better in performance and operational cost as compared to all previous GW treatments using the EC process, as shown in Table 4, which is an evaluation of the performance and cost of ECF for GW treatment.

**Table 4.** Comparative results of Greywater treatment with Electrocoagulation Process.

| Greywater Treatment | CD/V | EC | Electrode Material | Energy Required | Re % | OP Cost INR/$m^3$ | Ref. |
|---|---|---|---|---|---|---|---|
| Electrocoagulation and Disinfection | 135 V | BP-S | Al-Al | 3.5 kWh/$m^3$ | 60 % (COD) 65%(Turbidity) | 18.90 | [9] |
| Electrocoagulation | 10 V | MP-P | Al-Al-Al-Al | 0.03 kWh/$m^3$ | 70 % (COD) 85%(Turbidity) | 12.60 | [3] |
| Electrocoagulation and 0.45 (micro-m) Millipore membrane | 10mA/$cm^2$ | MP-P | Al-Fe-Fe-Al | 9.45 kWh/$m^3$ | 96 % (COD) 65% (SO4)2- 71% (Cl-) 92%(Turbidity) | Not Detected | [4] |
| Electrocoagulation and Filtration Unit in Batch Process | 24V | MP-P | Al-Fe-Al-Fe | 4.25 kWh/$m^3$ | 93 % (COD) 92% (TDS) 92% (Cl-) 95%(Turbidity) | 21.27 | [Present Study] |
| Electrocoagulation and Filtration Unit in Continuous Process | 24V | MP-P | Al-Fe-Al-Fe | 4.75 kWh/$m^3$ | 88 % (COD) | 21. 62 | [Present Study] |

* INR- Indian Rupees

## 4. Conclusions

Electrocoagulation coupled with sand-bed purification and carbon adsorption effectively treated the GW sample in a continuous mode with four different electrode combinations, namely Al-Fe-Al-Fe, Fe-Al-Fe-Al, Al-Al-Al-Al, and Fe-Fe-Fe-Fe, were investigated to successfully reduce the turbidity, TDS, TSS, and COD levels. The results highlight that removal efficiencies decrease with an increase in the flow rate, and results showed that a flow rate of 0.05 lit/min for the hybrid electrode provided

improved results when compared to the 0.1 lit/min flow rate; additionally, the pH significantly influenced the treatment efficiency, with the lower range of 7.3-8.0 yielding optimal results. The findings for the cost parameter revealed that the most cost-effective electrode combination is Al-Fe-Al-Fe, which consumes less energy and electrodes at all current voltages from 6, 12, and 24 V; additionally, this combination has a lower energy and electrode consumption. For continuous flow, the amounts required are INR 21.62/$m^3$ and INR 20.54/$m^3$ (for 0.05 lit/min and 0.1 lit/min, respectively). Overall, the Al-Fe-Al-Fe combination produced excellent results in terms of the removal efficiency while incurring lower operational costs. This research indicates that EC, combined with a sand-bed filter and activated carbon adsorption, can be a promising and sustainable method to treat greywater. By effectively treating and reusing greywater, decision-makers can contribute to water conservation efforts and mitigate water scarcity challenges.

## 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 no conflict of interest.

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