International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2025: 7.089

Electrochemical Coagulation Treatment of Hospital Wastewater: A Case Study of VDGMC Latur

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Abstract: ***Hospital wastewater is an complex effluent water that is rich in organic content, suspended solids, pathogens, and chemical pollutants and this poses a high environmental and human health hazard. The paper is research conducted to determine the nature of wastewater produced in VDGMC Latur hospital and to explore the application of electrochemical coagulation (EC) as a high-tech treatment process. The first analysis showed a high level of the Biochemical oxygen demand (BOD: 320 mg/L), Chemical oxygen demand (COD: 890 mg/L) and Total suspended Solids (TSS: 420 mg/L) and microbial contamination (106 MPN/100 ml), which are above the allowable discharge limits. The Water Quality Index was used to show that the wastewater was in the category of inappropriate. Different materials of electrodes (carbon, aluminum, and copper) and natural coagulants (Cicer arietinum, radish and Nirmali seeds) were used in conducting experimental studies. The outcomes revealed that COD, turbidity, and TSS removal efficiencies were highest at 85, 90 and 44.4 percent respectively at the optimal EC optimal conditions. Electrolysis time played a major role in the system performance, as the removal efficiency decreased as the duration of the electrolysis process decreased. The paper concludes that electrochemical coagulation is an effective sustainable and cost-effective method of treating hospital effluents. It can replace conventional methods with safer, eco-friendly treatment.***

Keywords: Electrochemical Coagulation, Hospital Wastewater, BOD, COD, WQI, Pollutant Removal

1. Introduction

Hospital wastewater refers to a multifaceted and dangerous effluent produced in the hospitals, and it is composed of a great variety of pollutants, including pharmaceuticals, pathogens, heavy metals, and organic substances. The sources of these pollutants are a number of hospital activities such as laboratories, wards, surgical units, and cleaning activities hence the wastewater is very heterogeneous in nature [31], [33]. The occurrence of antimicrobial compounds and pharmaceutical residues in hospital effluents is a very serious problem to the environment such as the emergence of antibiotic resistance and toxicity to aquatic organisms [4], [34].

Moreover, the hospital wastewater may cause toxic substances like heavy metals to accumulate in the receiving water bodies and sediments due to the untreatment or poor treatment of the wastewater, and this consequently impacts on the ecosystem and human wellbeing [5], [37]. A number of reports have stated that hospital effluents tend to surpass the discharge limits permissible in Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and microbial contamination, and effective treatment strategies are required [22], [7].

Biological and physicochemical processes are typical conventional wastewater treatment methods, which are usually vulnerable to eliminating the complex and non-biodegradable pollutants commonly found in the hospital wastewater [9], [36]. That is why, sophisticated treatment technologies are getting much attention in recent years. Of them all, electrochemical coagulation (EC) has been identified as a promising and efficient method of treating wastewater because it can produce coagulants in the environment, minimizes the utilization of chemicals, and also offers high efficiency in the removal of pollutants [13], [19].

Electrochemical coagulation is the process that includes dissolution of metal electrodes like aluminum or iron under the effects of electric current, resulting into the creation of metal hydroxides that stimulate the removal of contaminants by coagulation, adsorption, and flotation methods [23], [12]. A number of studies have shown the efficiency of EC in the treatment of industrial wastewater and hospital wastewater, which obtained great decrease in the organic load, turbidity and toxic contaminants [3], [11], [34].Thus, the proposed research will be focused on the analysis of the electrochemical coagulation performance towards the hospital wastewater treatment in the VDGMC Latur, considering the efficacy of pollutant removal and optimization of the process.

2. Objectives of the Study

The objective of the current research is to assess the performance of the electrochemical coagulation (EC) as a treatment method of the hospital wastewater produced in VDGMC Latur. The particular objectives of the research are the following:

1) To compare the performance of the electrochemical coagulation (EC) in treating the VDGMC Latur hospital wastewater.
2) To monitor the elimination of major pollutants in the form of Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), turbidity, total suspended solids and pathogenic microorganisms.

3) To maximize significant operational conditions of the EC process, such as, current density, pH, electrode material, and electrolysis time, to obtain the optimum treatment efficiency.

3. Study Area Description

The experiment carried out at Vilasa Deshmukh Government Medical College (VDGMC), Latur, Maharashtra aimed at describing and treating hospital wastewater. The samples of wastewater were taken at the major point of discharge of the hospital i.e. at the joint discharge of the effluents like the manhole of the sewage collection or the septic tank outflow. This site is a wastewater produced by numerous units of a hospital such as wards, laboratories, outpatient departments (OPD), and other auxiliary units, which creates a complicated and heterogeneous composition [31], [33]. Composite and grab sampling methods were used to conduct sampling to have a representative evaluation of the quality of wastewater. The samples (composite samples) were collected during a time span of 4 8 hours to consider the time variations and grabbed samples were to analyze particular parameters. It was collected in the laboratory-scale electrochemical coagulation experiments of approximately 20 30 liters of raw wastewater, with other aliquots held back to be used in further physico-chemical and microbiological characterisation. All samples were taken in clean acid washed high density polyethylene (HDPE) or glass containers so as to keep off contamination. Samples were properly preserved to maintain their quality. General physico-chemical samples were stored at 4 o C and performed within 24-48 hours. To analyse heavy metal, the samples were acidified by the use of nitric acid (HNO 3) to pH < 2 then refrigerated. Microbiological samples were treated under cold chain conditions and analyzed within the suggested holding time so as to ensure reliability of results [22]. In addition to sampling, detailed metadata was documented, including date and time, ambient weather, wastewater temperature, flow conditions, and visual observations (color, odor, and turbidity). These observations were used as useful background knowledge to interpret variations in wastewater characteristics as well as to interpret the results of the analytical results correctly.

4. Electrochemical Coagulation Principles

Electrochemical coagulation (EC) is a modern method of water and wastewater treatment, which implies the in situ production of coagulants when an electric current is applied. The fundamental principle of EC consists in dissolving metal electrodes, that is, aluminum or iron, in the wastewater. Upon the application of direct current, metal ions are debarked off the anode and consequently are hydrolyzed to produce metal hydroxides, which serve as coagulants. These coagulants destabilize and soil suspended and dissolved pollutants so that they are removed easily [13], [23]. The electrodes are important in the EC process. Aluminum and iron are the most widely used materials in the form of electrode owing to its efficiency, availability, and cost-effectiveness. Aluminum electrodes generate aluminum hydroxide flocs and iron electrodes generate iron hydroxides that have a high adsorption capacity of a variety of pollutants. The choice of the electrode material has a great impact on the efficiency of treatment, sludge properties, and the overall performance of the process [19], [24]. The electrochemical reactions take place concurrently at the anode and cathode. Oxidation occurs at the anode, and leads to the dissolution of metal and the formation of metal ions (Al 3 + or Fe 2 +/Fe 3 +). Reduction reactions take place at the cathode and these reactions usually consist of the production of hydrogen gas and hydroxide ions. The bubbles of hydrogen gas that are produced at the cathode also help in the flotation of the flocs, and thus increases the separation of the contaminants in the treated water [12], [23]. The major benefit of EC is that the coagulants are naturally formed in-situ and therefore, these chemicals do not need to be added externally. The metal hydroxides produced produce gelatinous flocs that have a high surface area and hence allow effective adsorption and entrapment of the pollutants. These flocs combine suspended solids, organic materials, heavy metals and microorganisms to larger sizes that can easily be removed [13], [19]. The EC process removes pollutants by several processes such as adsorption, the contaminants stick to flocs of the hydroxide, precipitation, the dissolved contaminants combine to form an insoluble product and electroflotation whereby gas bubbles carry the flocs to the surface so as to be separated. These mechanisms combined together have rendered the electrochemical coagulation very effective in the treatment of complicated wastewater, especially hospital effluents [3], [34].

5. Materials and Methods

5.1 Materials Used

The materials employed in the current research were the various forms of electrode materials and natural coagultants to undergo electrochemical coagulation (EC) process. Carbon, aluminum, and copper were chosen as the electrodes because the electrodes are effective, wastewater treatment applications, and good electrical conductors. The natural coagulants in the study were Cicer arietinum (chickpea), radish seeds, and Nirmali seeds (Strychnos potatorum), as they are known to be coagulants with the eco-friendly features [14], [25]. Natural coagulants are used, which decreases the utilization of chemical additives and improves the sustainability of the process of treatment [25].

5.2 Preparation of Natural Coagulants

The natural coagulants were also made in accordance with the common procedures in the literature. Cicer arietinum, radish, and Nirmali seeds were picked, washed ample times to get rid of the impurities and then dried either in the sun or in a regulated oven. The mixture was then dried using a mechanical grinder to form a fine powder. To remove the variation of particle size, the powdered samples were sifted and kept in airtight containers to avoid absorption of moisture and contamination. In other experiments, the coagulants were suspended in distilled water in order to make a homogeneous solution of the crushed coagulants [14].

5.3 Experimental Design

The experiment was done by taking the various combinations of electrode materials and natural coagulants to test how effective they are in the removal of pollutants. The electrodes contained carbon, aluminum and copper separately in combination with each of the coagulants, Cicer arietinum, radish seeds and Nirmali seeds. Therefore, nine electrodecoagulant combinations were run under the same operating conditions. All the experiments were also conducted in batch mode to facilitate a systematic comparison of the treatment efficiencies of the various combinations [19], [24].

5.4 Electrochemical Coagulation Setup

The laboratory experiments of the electrochemical coagulation were carried out in a batch reactor in a laboratory. The reactor was made up of a cargo container fitted with electrodes forming a monopolar parallel scheme of which current would be distributed evenly. The electrodes were mounted at a constant separation between electrodes. The electrodes were interconnected to a direct current (DC) power supply to provide the needed level of voltage and current. Each of the experimental runs involved a fixed amount of hospital wastewater, and the system was run under controlled laboratory conditions [12], [23].

5.5 Operational Procedure

In both experiments, the sample of the wastewater was treated with a known dosage of natural coagulant. The PH of the solution was measured and regulated when necessary to maximize the performance of the treatment. The EC process was also initiated by subjecting the electrodes to an electric current at a given electrolysis period which normally lasted between 10 and 60 minutes. Once the electrolysis process had been completed, the treated water was left to settle over a given period of time to allow the separation of the flocs that had been formed during the coagulation process. The resulting clarified supernatant was then carefully harvested and had an additional physico-chemical analysis performed on it [13], [23].

5.6 Parameters Monitored

The effectiveness of the electrochemical process of coagulation (EC) was considered through the analysis of the main physico-chemical parameters prior and after treatment. These were; pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and oil and grease content. The parameters were chosen to comprehensively evaluate the efficacy of treatment and the ability of the pollutant removal since they are commonly used parameters of wastewater quality and organic load [22], [31].

5.7 Analytical Methods

The strength of all the analyses was based on the recommended standards by American Public Health Association (APHA), Central Pollution Control Board (CPCB) and the World Health Organization (WHO). These standardized procedures provided accuracy, reliability, besides comparability of the results gained in dissimilar experimental runs. Parameters like COD, BOD, and TSS were also observed with defined parameters of analysis that ensured the quality and consistency of data [22].

5.8 Data Analysis

Standard removal efficiency equations were used to compute the efficiency of the pollutant removal depending on the start and the final concentration of the respective parameters. The various combinations of electrode and coagulant were put to test to determine the best study arrangement with respect to hospital wastewater. Also, statistical analysis, mean and standard deviation, was carried out to assess the consistency, reproducibility and reliability of the experiment findings [19], [24].

6. Results and Discussion

6.1 Initial Characteristics of Hospital Wastewater

Figure 1 reflects the physico-chemical properties of a wastewater collected by VDGMC Latur. The analysis shows that the pH (7.4) and temperature (27 C) are within acceptable limits as defined by CPCB/WHO standards but that a number of the critical parameters are way beyond the acceptable limits. Biological Oxygen Demand (BOD = 320 mg/L), Chemical Oxygen Demand (COD = 890 mg/L), and Total Suspended Solids (TSS = 420 mg/L) are at high concentration which means that the pollutant load of the water is high based on organic and particulate pollution. Oil and grease (28mg/L) and phosphorus (10mg/L) are also over the permitted limits. Also, fecal coliform count (10 6 MPN/100 ml) affirms extreme contamination by microbes. This shows that the wastewater is highly contaminated and cannot be discharged directly to the environment without treatment.

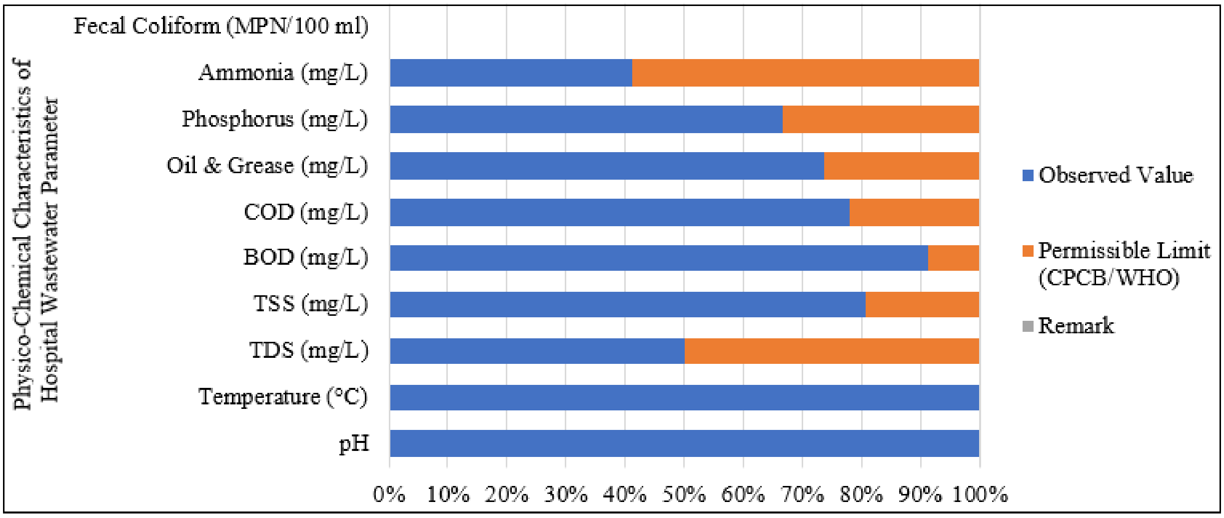

Figure 1: Physico-chemical characteristics of wastewater collected from VDGMC Latur

6.2 Wastewater Analysis of parameters using statistics

Figure 2 displays the statistical data on parameters of wastewater such as mean and standard deviation. According to the obtained analysis, the consistency and variability of the main physico-chemical characteristics of the hospital wastewater can be observed. The average values of the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) were 320 mg/L, 888 mg/L, 422 mg/L, and 2100mg/L respectively, showing that there is a very high rate of organic and inorganic pollution. The relatively small value of standard deviation of all these parameters (BOD: 15.81, COD: 28.64, TSS: 19.24, TDS: 38.08) indicate that the characteristics of the wastewater do not vary significantly throughout the sampling period and the values are rather stable. This consistency is a constant and unchanging release of pollutants produced by the hospital operations including laboratories, wards and cleaning activities. More so, the variability of parameters like oil and grease, ammonia and phosphorus was also low meaning that there was a consistent presence of these contaminants in the wastewater stream. The statistical findings prove that the wastewater is regularly contaminated, and it contains a high organic load, which supports the necessity of implementing a powerful and trustworthy treatment technique like the electrochemical coagulation.

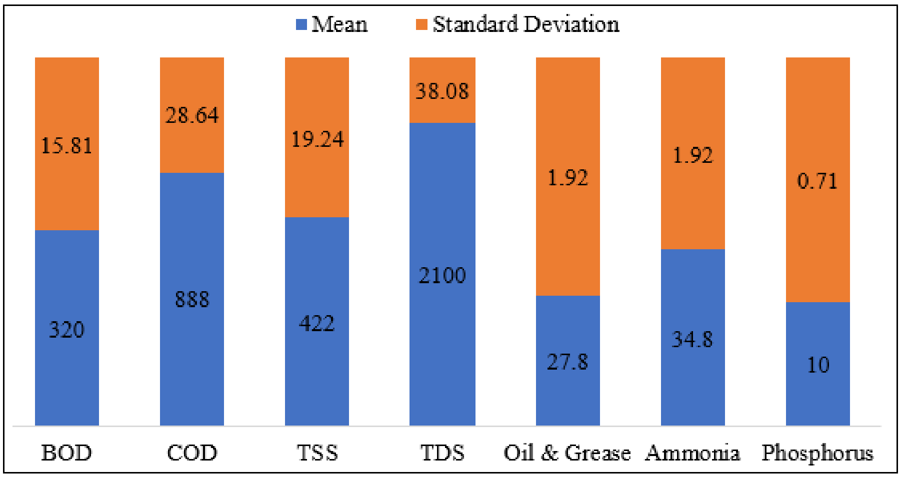

Figure 2: Statistical Analysis of Wastewater Parameters

6.3 Correlation Analysis

Correlation analysis (Figure 3: Correlation Heatmap) indicates that there is a positive relationship between BOD, COD, and TSS that is strong. There was a high positive correlation between Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS), which showed that the three measurements are closely related and are mostly dependent on the organic load that is introduced by the hospital wastewater. The more the BOD values, the higher the COD and TSS levels are, which is why it can be concluded that the wastewater has a lot of biodegradable and non-biodegradable organic substances.

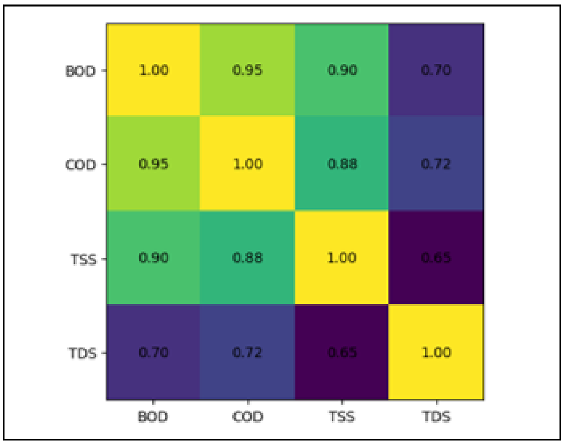

Figure 3: Correlation Heatmap of Wastewater Parameter

6.4 BOD/COD Ratio Analysis

Figure 2 is a plot of Biochemical Oxygen Demand (BOD) versus Chemical Oxygen Demand (COD) in the hospital wastewater in the form of the ratio of the BOD to COD. The ratio is a key parameter of biodegradability of wastewater. The BOD value is 320 mg/L and COD value is 890 mg/L giving a ratio of BOD to COD of about 0.36. This shows that the wastewater is moderately biodegradable that is to say that some of the organic material can be biologically processed and the rest is non-biodegradable or slowly degradable material. The rather moderate ratio as presented in Figure 4 indicates the existence of complex pollutants including pharmaceuticals, chemicals, and others that usually occur in hospital wastewater. Hence, traditional biological treatment might not be adequate and the emerging treatment strategies like electrochemical coagulation need to be employed to treat the pollutants.

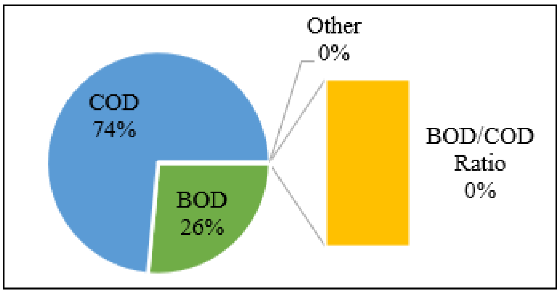

Figure 4: BOD/COD Ratio Analysis Graph

6.5 Water Quality Assessment

Water Quality Index (WQI) was calculated to assess the overall position of hospital wastewater by incorporating a combination of physico-chemical parameters that includes; pH, BOD, COD, TSS, TDS, phosphorus, and ammonia. The calculated value of WQI was established at about 420, which was a very poor water quality. The high value is mostly due to high concentration of BOD (320 mg/L), COD (890 mg/L) and TSS (420 mg/L), which are high loads of organic and suspended pollutants. WQI standard classifications set those values over 300 in the category of unsuitable to drink. Further on, as Figure 5 demonstrates, the role of each parameter in the total WQI indicates that BOD and COD are the most dominant factors of water quality deterioration. As evidenced in the results, the hospital wastewater is very contaminated and needs proper treatment before discharge and hence there is a need to apply sophisticated methods in treating water like electrochemical coagulation.

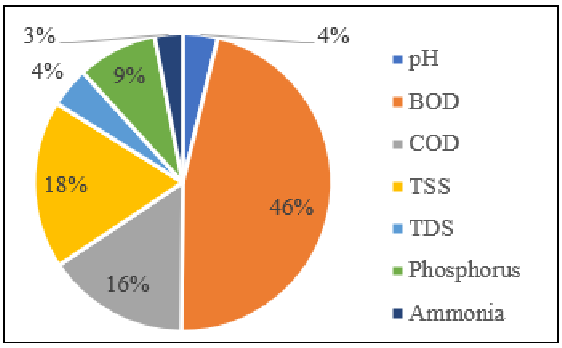

Figure 5: Wastewater Hospital Wastes Water Quality Index (WQI)

6.6 Impact of Electrochemical Coagulation (EC) Treatment

6.6.1 Effect of Electrolysis Time

The impact of the time of electrolysis to the efficiency of pollutant removal can be seen in Figure 4. It was noted that the removal efficiency of important pollutants including Chemical Oxygen Demand (COD), turbidity and Total Dissolved Solids (TDS) improved gradually with the rise in the electrolysis time. During the first stage (10 minutes), the removal efficiencies were not so high; COD, turbidity, and TSS removals were 32, 41.7 and 15.6. When the period of the electrolysis was raised to 30 minutes, there was a great gain of the removal efficiency as the dissolution of the material on the electrode was enhanced and more coagulant species were formed. During longer durations of the electrolysis (40-60 minutes), the changes in efficiencies of the removals were optimum whereby a maximum of 85-percent COD removal, 90-percent turbidity removal and 44.4-percent TDS removal were realized after 60 minutes. The latter can be explained by the fact that metal hydroxide flocs continue to be produced, that is successful in adsorbing and trapping pollutants, and the evolution of hydrogen gas that contributes to flotation. Nevertheless, it can be seen that after the optimal time, any additional increase in the time of the electrolysis process might not cause a significant enhancement and might cause a higher energy use. Figure 6 illustrates that turbidity removal was always better than those of COD and TDS removal, which shows that electrochemical coagulation is especially effective at removing turbidity in suspended and colloidal forms. In general, the findings indicate that the time of electrolysis is an important functional factor that affects the effectiveness of the electrochemical coagulation process.

Paper ID: SR26327152644 DOI: https://dx.doi.org/10.21275/SR26327152644

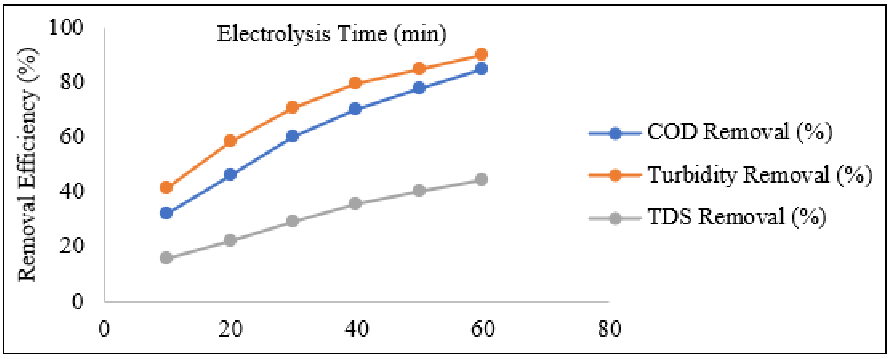

Figure 6: The Effect of Electrolysis Time on the Pollutant Removal Efficiency

6.6.2 Efficiency of Removal of Pollutants

Figure 5 shows the removal efficiencies of Chemical Oxygen Demand (COD), turbidity, and Total Dissolved Solids (TSS). The findings indicate that the phenomenon of electrochemical coagulation (EC) is extremely effective in lowering the level of pollutants in the hospital wastes. Turbidity was found to be the most effective parameter with a maximum removal efficiency of 90 percent and this showed the great ability of EC to remove suspended and colloidal particles by way of coagulation and electroflotation processes. The removal efficiency of COD was also high with a maximum of 85 percent which can be associated with effective removal of the organic pollutants contained in the waste water. This decline is qualified mainly to the fact that metal hydroxide flocs are formed, which precipitate dissolved organic matter and adsorb it. Conversely, TDS removal was relatively less with a maximum efficiency of 44.4 since dissolved solids are harder to remove and need more time to be treated or further treatment. Figure 7 has shown that the general tendency shows that the higher is the time of electrolysis, the more efficient the removal of the pollutants, which is why the optimization of operations is important. The findings affirm that electrochemical coagulation is especially effective in the reduction of turbidity and organic load, whereas the partial elimination of dissolved solids is also possible. Hence, EC may be believed to be a valuable and efficient method of wastewater management in hospitals.

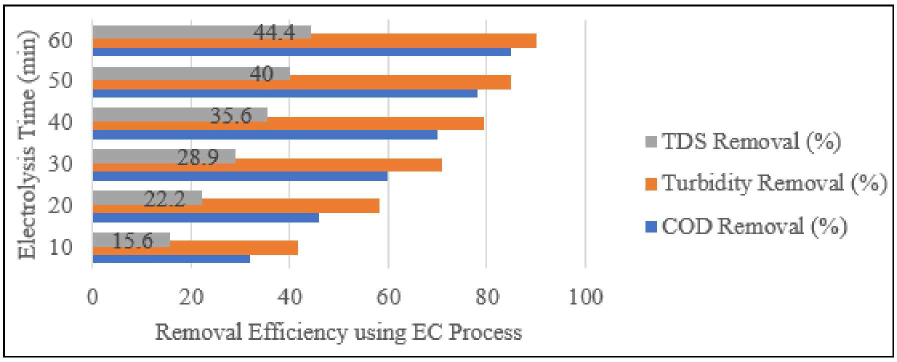

Figure 7: Removal Efficiency of Pollutants by EC Process

6.7 Electrode Coagulant Combinations Performance

The use of various electrode materials (carbon, aluminum and copper) and the natural coagulants (cicer arietinum, radish seeds as well as Nirmali seeds) was tested. These included aluminum electrodes, which performed better as a result of the well formed metal hydroxide flocs. Natural coagulants were also added, which increased the removal of the pollutants due to better adsorption and flocculation processes, which is synergistic.

6.8 Process of Removing Pollution

The elimination of pollutants during electrochemical coagulation process has several processes such as coagulation, adsorption, precipitation and electroflotation. At the anode, metal hydroxides are formed which are used as coagulants and capture suspended and dissolved pollutants. The cathode evolution of hydrogen gas helps in flotation, which helps in separating the flocs. Development of floc and adsorption capacity is further improved by natural coagulants.

7. Conclusion

The current work examined the nature of hospital wastewater in VDGMC Latur and examined the suitability of electrochemical coagulation (EC) to treat the wastewater. The wastewater was found to be very toxic, with a high concentration of BOD (320 mg/L), COD (890 mg/L), TSS (420 mg/L), and microbial contamination (10 6 MPN/100 ml) which surpassed the discharge limits. The Water Quality Index (WQI) also established that the wastewater is in the category of unsuitable to be discharged which means that the wastewater should be effectively treated.

Electrochemical coagulation process showed a high removal capacity of major pollutants. In optimized conditions, maximum COD, turbidity and TDS removal efficiencies of about 85, 90, and 44.4 percent were obtained respectively. The findings further showed that the duration of the electrolysis is essential to the performance in treatment with more removal efficiencies when the duration is longer

Paper ID: SR26327152644 DOI: https://dx.doi.org/10.21275/SR26327152644

because of the improved generation of coagulant species, and a better aggregation of the pollutants.

The parameters that were studied have shown that turbidity removal was the most effective, then COD, TSS removal was rather moderate. The results affirm the fact that EC is especially appropriate in taking away suspended and organic contaminants within hospital wastes. The treatment was also improved by using various electrode materials and using natural coagulants.

Altogether, it can be seen that electrochemical coagulation is an effective, promising, and environmentally friendly method of treating hospital wastewater. Its pros include the minimization of chemicals used, efficient elimination of pollution and ease of use. Thus, EC could be regarded as one of the options that could be used as an alternative to traditional treatment techniques of wastewater management in medical centers.

Acknowledgement
The authors have heartily recognized the role and contribution of ABMSP an Anantrao Pawar College of engineering and Research (APCOER), Pune in giving the required support and facilities to conduct the research work. We are also greatly grateful to Ms. Supriya Baban Shinde (Project Guide) and Mr. Sagar Gawande (PG Coordinator) who provide us with great help and assistance.

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