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Performance assessment of electrode materials in the treatment of leachate by using electrocoagulation process

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ABSTRACT

Leachate is wastewater generated during the decomposition of organic waste that can contaminate soil and groundwater if it is not handled properly. Contamination by leachate can be prevented by reducing the concentration of a pollutant in leachate before the wastewater reaches the ground. Researchers reduce the contamination level by the various method and electrocoagulation is one of the efficient methods for this application. This experimental work was planned to determine the effective pair of the electrode and optimizing the factors which affect the efficiency of electrocoagulation. From the first study, it may be concluded that Iron and Stainless steel pair show higher percentage removal of all the analyzed parameter than the copper and stainless steel pair. Then optimization was carried out with Iron and Stainless steel electrode to analyze the effect of current density, pH, and inter-electrode distance, the concentration of electrolyte, electrolysis time and agitation on electrocoagulation. The optimized current density was determined as 60A/m2, electrolysis time was determined as 45 minutes, the inter-electrode distance was determined as 1.5 cm, pH was determined as 7.4, agitation speed was determined as 300 rpm, electrolyte solution was determined as 25% dilution.

Keywords— *Electrocoagulation, Leachate, Iron, Copper, Stainless steel*

1. INTRODUCTION

Landfilling is the most common and easy way to dispose of solid waste. The landfill has commonly received the wastes from municipal near to a landfill. If the location of waste generated is far, the transfer station is the solution to reduce the cost of waste transportation. The waste usually mixed of waste products from the residential area, commercial, institutional and others. There are three kinds of output for landfills, examples gas, liquid (leachate) and inert solids [1]. Leachate has a complex structure and high pollutant load, and its treatment is quite hard to meet the discharge standards. Leachate becomes the main pollutant wastewater since it is the most difficult to treat as it is wastewater with complex and widely variable content generated within a landfill [2]. Leachates may contain organic contaminants in large amounts and can be measured as Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), ammonia, and high concentration of heavy metals. It contains a high concentration of pollutants which can have adverse effects on the environment [3]. Therefore, many pre-treatment and combined treatment methods have been proven to treat leachate. Until today, many methods for its treatment have been proven. Some well-known treatment methods such as biological treatment methods, membrane processes, advanced oxidation techniques [4], coagulation-flocculation methods, lagoon and wetland applications [5], have been examined in the literature. Simple, affordable, and efficient leachate treatment systems are urgently needed in developing countries because most of the conventional technologies currently in use in industrialized nations are too expensive and complex. Electrocoagulation is one of a simple method to treat wastewater efficiently [4]. This electrochemical treatment seems to be a promising treatment method due to its high effectiveness, its lower maintenance cost, less need for labor and rapid achievement of results. Electrocoagulation has been used in treating wastewater containing oil and grease, suspended solids and even inorganic and organic pollutants that can be flocculated. This method is categorized by simple equipment and easy operation. The electrocoagulation processes have a lesser amount of sludge [6] and having features like relatively more economic and higher treatment efficiency has been a promising method [7]. Actually, different alternatives are used to treat leachates, such as biodegradation (both aerobic and anaerobic techniques), physicochemical treatments like coagulation/flocculation, chemical precipitation, adsorption, chemical oxidation and leachate transfer. Additionally, physical and chemical processes are usually used as a pre-treatment to remove suspended solids, colloidal particles, floating material and color or as a treatment to remove. Organic matter from the non-biodegradable leachate [9]. In recent years, Electrocoagulation (EC) has been under study as an alternative to traditional wastewater treatment processes. This process is an electrochemical method based on the destabilization of suspended, emulsified or dissolved pollutants in an aqueous medium by the in situ metal dissolution of a coagulant from a sacrificial anode with the simultaneous formation of the hydroxyl ion and hydrogen gas at the cathode [1, 12, 13]. EC promotes coagulation, flocculation and even the flotation of particles in the same cell [2].The electrocoagulation process has been used for over a century to overcome the drawbacks of conventional wastewater treatment technologies. This has been applied to several effluents, including textile wastewater, vinasse, landfill leachates clay suspensions and acidic leachates of soils contaminated with heavy metals [20]. Some of these investigations have shown that electrocoagulation process is effective to remove a wide range of pollutants: Organic load and toxic metals as copper, chromium, mercury, lead, cadmium and some case to remove algae and microorganism. Electrocoagulation is also used to the destruction of algae and microorganism and to reduce the turbidity and color. Benefits from using this process include relatively low cost, less sludge formation, easy operation, less equipment requirement, shorter treatment period, versatility, safety, amenability to automation and environmental compatibility. Also, electrocoagulation can be adapted to treat leachates from different age and different composition.

1.1 Electrocoagulation

Water is also electrolysed in a parallel reaction, producing small bubbles of oxygen at anode and hydrogen at the cathode. Electrocoagulation, precipitation of ions (heavy metals) and colloids (organic and inorganic) using electricity has been known as an ideal technology to upgrade water quality for a long time and successfully applied to a wide range of pollutants. Electrocoagulation is the technique to create conglomerates of the suspended, dissolved or emulsified particles in aqueous medium using electrical Current causing production of metal ions at the expense of sacrificing electrodes and hydroxyl ions as a result of water splitting. Metal hydroxides are produced as a result of EC and act as coagulant/flocculent for the suspended solids to convert them into flocs of enough density to be sediment under gravity. Destabilization of the contaminants, particulate suspension, breaking of emulsions, and aggregation of the destabilized phases to form flocs. The reactions occurring in an EC process using anode and cathode can be referred in Equation given below.

At the anode,

$$M \rightarrow M^{n+} + ne^{-}$$

At the cathode,

$$nH_2O + ne^{-} \rightarrow n/2\ H2 + nOH^{-}$$

Where M is the anode and n is the stoichiometric number of electrons within the oxidation or reduction reaction. Soluble metal ions (Fe or A1) are created at the anode and have reacted with the hydroxide ions created at the cathode. The metal hydroxides are generated as shown below:

$$M^{n+} + nOH^{-} \rightarrow M\ (OH)_n$$

The insoluble metal hydroxides precipitate after reacting with the colloid and suspended solids

2. MATERIALS AND METHODS

2.1 Leachate sample

The Leachate for the study was collected from Erode city Municipal Corporation managed by the Public Health Department of the Erode Municipal Corporation. Area of dumping yard is 27.37 acres. 10 litres of the sample was collected for the study. The sample was collected as a grab sample and thus collected was preserved as a stock solution in the refrigerator and used for further studies when required.

2.2 Experimental device

The electrocoagulation cell consists of the beaker, anode and cathode materials, magnetic stirrer and DC power supply. A beaker with a capacity of 500ml was taken as a batch reactor. The materials used in this study were Copper, Iron and Stainless steel electrode. The electrocoagulation unit consists of two electrodes of the same dimension (10cm x 5cm x 1mm). These electrodes were used as anode and cathode which are kept at a certain specific distance in the electrocoagulation cell. Before each run, electrodes were washed with water and dipped in hydrochloric acid in order to remove dust from the electrode plates. Anode was connected to the positive terminal of DC power supply and cathode was connected to the negative terminal of DC power supply. The whole setup was kept on the magnetic stirrer to maintain homogenous mixing of the solution in the reactor during the process. The line sketch of the proposed reactor was shown in figure 1.

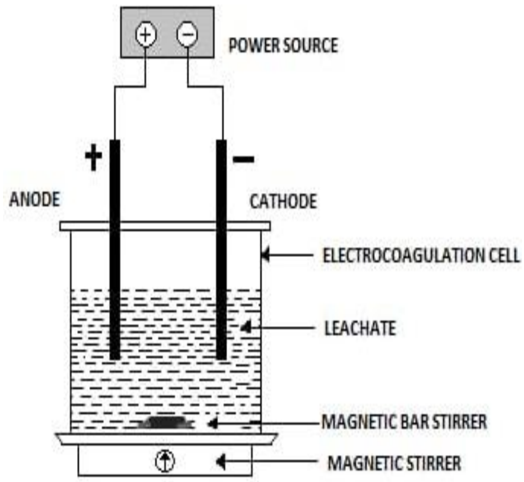

Fig. 1: Line sketch for the Proposed Reactor setup

2.3 Experiment procedure

The procedure started with the electrocoagulation cell cleaned with distilled water and dried using dryer. The experiments were carried out in a batch mode. For each experiment, a leachate sample of 500ml was collected in the electrochemical cell with Iron, Copper, Stainless steel electrodes dipped into the sample. The total experiments were carried out to determine the effect of current, inter-electrode distance, electrolysis time and effect of pH, agitation. The pH of the solution was taken using a pH meter. The electrodes (anode and cathode) were clamped at electrode stand. All connections in the circuit were completed by wire connection to terminal positive and negative to DC power supply, electrodes (anode and cathode). After the experiment, the treated sample was then kept undisturbed for 20 min in order to allow the flocs to settle. Subsequently, after settling the sample of supernatant was collected to perform the analysis of pH, TDS TSS, COD, chlorides and sulphates. All the experiments were repeated with the same operational conditions using Iron and Copper electrode as anode and Stainless Steel electrode as a cathode. For the treated effluent COD, TSS, TDS, Sulphates, chlorides were measured according to Standard Methods after each batch run.

3. RESULTS AND DISCUSSION

The electrocoagulation process was influenced by operating parameters such as current, electrolysis time, inter-electrode distance, pH, agitation on the removal of COD, TSS, TDS, chlorides and sulphates

3.1 Characteristic of the landfill leachate

Characteristics are shown in table 1.

Table 1.Initial characteristics of leachate

S no.	Characteristics	Unit	Value
1	pH	-	7.43
2	Turbidity	NTU	253
3	Conductivity	µS/cm	6600
4	Total Suspended solids	mg/L	4555
5	Total Dissolved Solids	mg/L	4180
6	BOD	mg/L	225
7	COD	mg/L	20000
8	Chlorides	mg/L	3229
9	Sulphates	mg/L	3045

3.2 Comparative Studies

The maximum removal efficiency was obtained by using Iron and Stainless Steel electrode when compared with Copper and Stainless Steel electrode. Figure 2 shows the removal efficiency of the various parameter by using Iron and Stainless Steel pair, Copper and Stainless Steel pair as electrode materials.

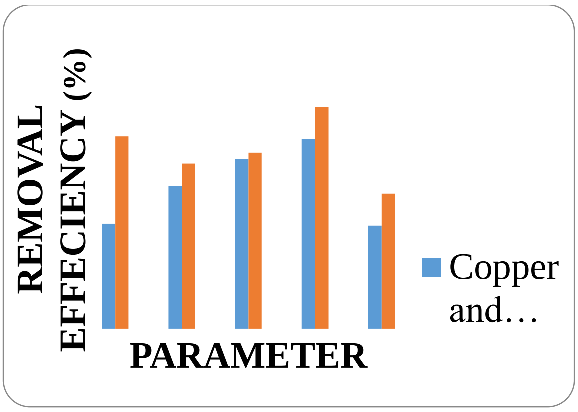

Fig. 2: Removal Efficiency

3.3 Effect of Current

The current density is an important operating factor which determines the coagulant dosage. The investigated current densities were 0.2, 0.4, 0.6, 0.8, and 1.0 (A). Figure 3 depicts the effect of current density on the removal efficiencies by the following conditions: 7.43 pH, 30 min electrolysis time. The removal efficiency of COD at current density 0.2 to 1 A increase from 47% to 70% and from 45 % to 71% for TDS, and from 45 % to 66% for TSS removal, and from 47 % to 70% for Chlorides and from 44 % to 72% for Sulphates it does not change significantly at higher current density. By the increasing of current density, the extent of anodic dissolution of iron increases, resulting in a greater amount of hydroxide flocs for the removal of pollutants. Moreover, the rate of bubble-generation increases and the bubble size decreases with the increasing of current density, resulting in faster removal of pollutants by H2 flotation.

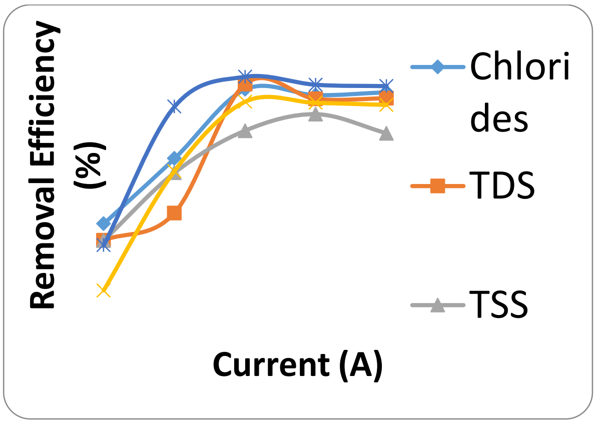

Fig. 3: % Removal efficiency by varying current

3.4 Effect of Electrolysis Time

The effect of electrolysis time was investigated in the range 15 to 60 minutes by the following conditions: 7.43 initial pH, 0.6 a current density values. As can be seen in Fig. 2, an increase in the time from 15 to 90 minutes yield an increase in the efficiency of COD removal from 56%to 71% and TDS removal from 49 to 76%, TSS removal from 57 to 81%, chlorides removal from 59%to 76% sulphates removal from 67 %to 72% it does not change significantly after 45 min. When the electrolysis time increases, the concentration of ions and their hydroxide flocs increase, also the rate of bubble-generation increases. The pollutants in leachate were removed by the effect of coagulation and flotation. High electrical energy consumption with the increasing time, the optimum time of electrolysis is 45 mins.

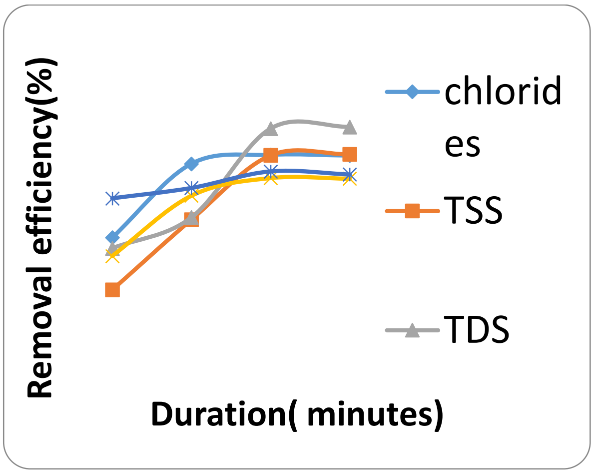

Fig. 4:% Removal efficiency by varying electrolysis time

3.5 Effect of Inter Electrode Distance

The effect of electrolysis time was investigated in the range 1 to 2.5 cm by the following conditions: 7.43 initial pH, 0.6 a current density values. As can be seen in figure 5, an increase in the distance from 1 to 2.5cm yield an increase in the efficiency of COD removal from 56%to 71% and TDS removal from 62 to 78%, TSS removal from 63 to 78%, chlorides removal from 69%to 75% sulphates removal from 69 %to 75% it does not change significantly after inter electrode 1.5 cm.

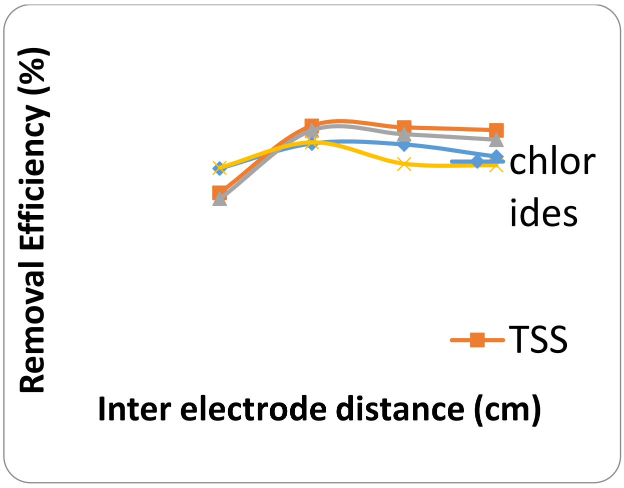

Fig. 5: % Removal efficiency by varying inter-electrode distance

3.6 Effect of pH

This study was carried out to investigate the efficiency of Iron & Stainless Steel electrode with various pH 5.4,6.4,7.4,8.4 and Constant Current, Inter-electrode distance, Electrolysis time, agitation, Electrolytic solution as 0.6A, 1.5cm, 45 minutes, 300rpm, 100% raw leachate in the electrocoagulation process for the removal of COD, Chlorides, Sulphates, Total Dissolved Solids, Total Suspended Solids from the leachate. The graph shows that the maximum removal efficiency for COD, TSS, TDS, Sulphates, Chlorides were 70.50, 79.71, 77.87, 76.22, 78.19 at pH of 7.4

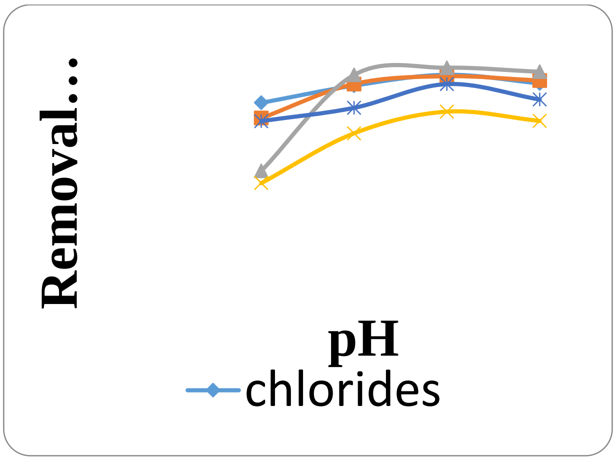

Fig. 6: % Removal efficiency by varying pH

3.7 Effect of agitation

This study was carried out to investigate the efficiency of Iron & Stainless Steel electrode with various agitation 100,200,300,400,500 rpm and Constant Current, Electrolysis time, pH, inter electrode distance, Electrolytic solution as 0.6A , 45minutes, 7.43, 1.5 cm, 100% raw leachate in the electrocoagulation process for the removal of COD, Chlorides, Sulphates, Total Dissolved Solids, Total Suspended Solids from the leachate. The graph shows that the maximum removal efficiency for COD, TSS, TDS, Sulphates, Chlorides were 75.5, 81.21, 78.56, 80.36, 82.53 at optimum agitation of 300rpm.

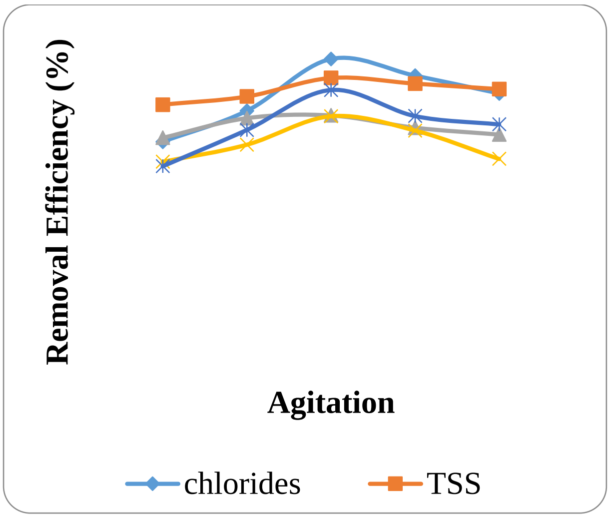

Fig. 7: % Removal efficiency by varying agitation

3.8 Effect of Electrolyte solution

This study was carried out to investigate the efficiency of Iron & Stainless Steel electrode with various electrolyte solution 25%,50%,75% and Constant Current, Electrolysis time , pH, inter electrode distance, agitation as 0.6A , 45minutes, 7.43, 1.5 cm, 300rpm in the electrocoagulation process for the removal of COD, Chlorides, Sulphates, Total Dissolved Solids, Total Suspended Solids from the leachate. The graph shows that the maximum removal efficiency for COD, TSS, TDS, Sulphates, Chlorides were 83, 82.21, 80.26, 85.68, 85.87 at electrolyte dilution of 25%.

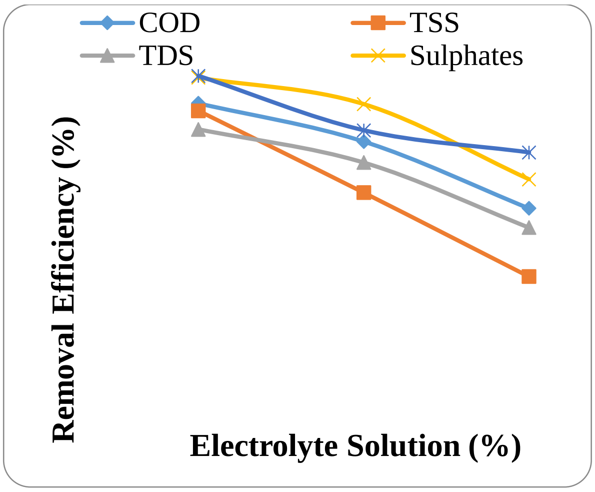

Fig. 8: % Removal efficiency by varying electrolyte solution

3.9 Sludge characterization

Knowing the sludge composition and surface condition would provide valuable information regarding EC removal mechanisms. In this study, Energy Dispersive Analysis of X-ray (EDAX) and Scanning electron microscopy (SEM) were used to characterize the sludge formed during the EC process.

3.9.1 Energy Dispersive Analysis of X-ray: Energy Dispersive Analysis of X-ray was used to analyse the elemental constituents of the sludge formed before and after optimization. Figure 6 and 7 confirmed the presence of chloride in the settled sludge. The other peaks indicate that iron, oxygen, aluminium, calcium, potassium are present in the sludge.

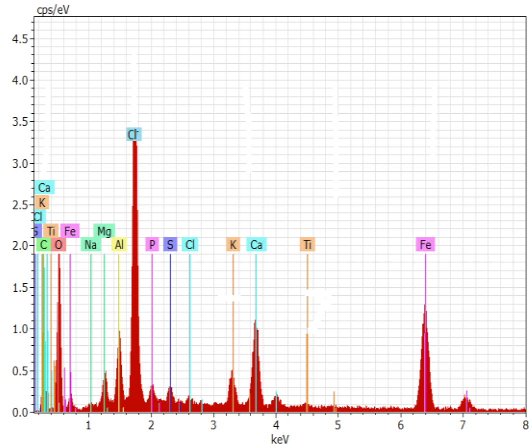

Fig. 9: EDAX of the sludge generated before optimization

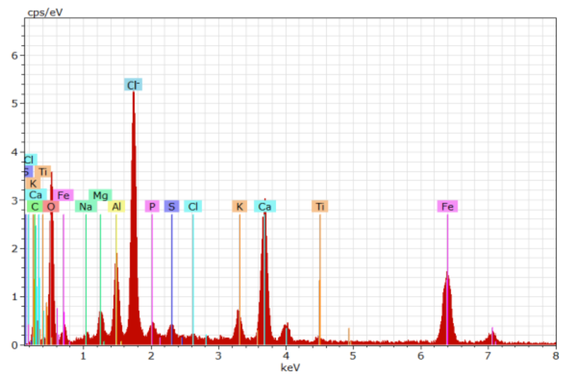

Fig. 10: EDAX of the sludge generated after optimization

3.9.2 Scanning Electron Microscopy: The SEM observation shows that the sludge formed by the treatment of the electrocoagulation before optimization were lumpy, amorphous structures and after optimization were porous, ultrafine particular structure scanned at micrometer size.

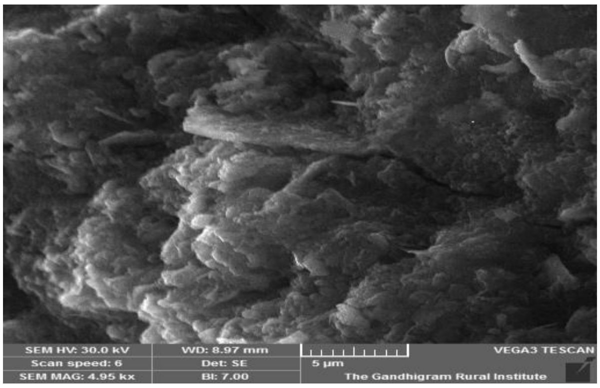

Fig. 11: SEM image of the sludge generated before optimization

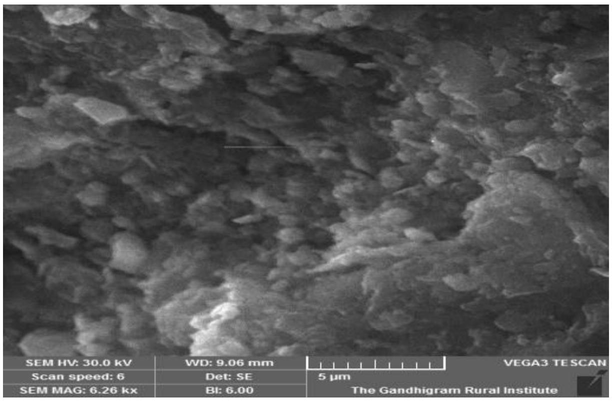

Fig. 12: SEM image of the sludge generated after optimization

4. CONCLUSION

Electrocoagulation is an efficient process to treat leachate characterized by the presence of high COD, Chlorides, Sulphates, TSS and TDS concentration. In this research, the study was conducted for the treatment of leachate by applying the electrocoagulation method. Iron and Copper electrodes as anode and Stainless steel electrodes as cathode were tested for their efficiencies with regard to Chlorides, Sulphates, TSS, TDS and COD reduction. This efficiency varies with the electrode material. The Leachate for the study was collected from Erode city Municipal Corporation managed by the Public Health Department of the Erode Municipal Corporation. The Leachate collected was characterized in terms of pH, Conductivity, Turbidity, TS, TSS, TDS, BOD, COD, Sulphates and chlorides as per the standard methods (American Public Health Association). Different sets of experimental studies will be carried out to optimize the various parameters carried out in Electrocoagulation process. The first experimental study of this project was carried out to find the removal efficiency by using Iron and Copper electrode as anode and Stainless steel as a cathode. The percentage of removal efficiency of TDS, TSS, chlorides, sulphates and COD by using Iron and Stainless Steel electrode are 66.50%, 57.18%, 60.87%, 76.58%, and 46.75% respectively. The percentage of removal efficiency of TDS, TSS, chlorides, sulphates and COD by using Copper and Stainless Steel electrode are 36.36%, 49.39%, 58.69%, 65.62%, and 35.7% respectively. From the result, it is observed that Iron and Stainless Steel electrode gives maximum removal efficiency than Copper and Stainless Steel. Then optimization was carried out with Iron and Stainless steel electrode to analyse the effect of current density, pH, and inter-electrode distance, the concentration of electrolyte, electrolysis time and agitation on electrocoagulation. The optimized current density was determined as $60A/m^2$, electrolysis time was determined as 45 minutes, inter-electrode distance was determined as 1.5 cm, pH was determined as 7.4, agitation speed was determined as 300 rpm, electrolyte solution was determined as 25% dilution. The results conclude that the electrode material plays an important role in the electrocoagulation method for treatment of leachate. Energy Dispersive Analysis of X-ray (EDAX) and Scanning electron microscopy (SEM) were used to characterize the sludge formed during the EC process. EDAX confirmed the presence of chloride in the settled sludge. The other peaks indicate that iron, oxygen, aluminium, calcium, potassium are present in the sludge. The SEM observation shows that the sludge formed by the treatment of the electrocoagulation before optimization were lumpy, amorphous structures and after optimization were porous, ultrafine particular structure scanned at micrometre size.

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