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Technical Review On Application of Electrocoagulation for the Treatment of Landfill Leachate

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ABSTRACT

Hazardous waste generation and its disposal in hazardous waste landfill is an unavoidable result of industrialization. The leachate producedfrom such landfills is very complex and toxic in nature and it possess huge potential to contaminate nearby surface and ground water resources. Therefore the collection and treatment of this leachate is essential for sustainable management of hazardous waste. Various conventional, chemical and advance processes have been applied to treat this most complex form of waste water but all technologies are associated with certain limitation and disadvantages. Major limiting factors are cost involved in treatment, operability of the process and huge sludge generation. Looking at the necessity to establish a competent treatment process which can overcome above mentioned limitations, Electrocoagulation was applied to check its efficiency for treating leachate. Electrocoagulation produces combined effect of chemical coagulation, floatation, precipitation and oxidation when applied efficiently. In this study, leachate from hazardous waste landfill was treated with electrocoagulation using aluminium electrodes. Efficiency of the process was checked at different sets of operating condition so that the results can be optimized. COD removal was taken as parameter of concern and the average COD removal through electrocoagulation was observed as 80%.

Keywords: Electroagulation, COD removal, landfill leachate, DC supply

1. INTRODUCTION

Rapid industrialization and urbanization has resulted in generation of huge quantities of solid waste in and its management has become one of the major environmental issues these days[3.0, 3.2]. Landfilling is one of the most prevalent method used by many countries to manage this ever increasing solid waste quantities round the globe[3.0]. These landfills over the period of time behave like a bioreactor where degradation of the organic fraction of solid waste takes place. Even landfills dealing with industrial waste undergo various physical and chemical changes, as a result of this process, a highly concentrated liquid is produced containing very complex characteristics and termed as leachate [1.5, 4.0].It has been reported that leachate contains large amounts of organic matter, ammonical nitrogen, heavy metals, and chlorinated organic and inorganic salts [1.5,3.3,3.4,4.2]which makes it very difficult to treat through conventional treatment technologies. Research is going on to develop more technologies which can efficiently treat this complex effluent. Different technologies developed for leachate treatment includes advanced oxidation processes, ion exchange, membrane filtration processes, coagulation, flocculation, electrocoagulation, ozonisation, ion resins adsorption, chemicals precipitation, lagoons and wetland [3.0,3.1,3.2,3.3,3.4,2.2,4.2,1.1]

However, leachate becomes an issue as a wastewater sources since it may cause serious pollutions to ecosystem. The heavy metals that commonly found in high concentrations in leachate are iron, manganese, zinc, chromium, lead, copper and cadmium. Therefore, more technological development had been done in various countries to treat the landfill leachate. [1.5,1.3,1.2,2.2,4.4]. Electrocoagulation which is a simple and efficient electrochemical procedure to purify water and wastewaters. It operates by way of precipitation of ions such as heavy metals and colloids, organic and inorganic compounds, coagulated by electricity. Electro coagulation (EC) is an advanced water treatment technology and used to remove a wide range of pollutants such as metal ions, suspended solids, colloidal solids, coloured compounds, dissolved solids, fat, oil, diesel, complex organic compounds, bacteria and viruses.

EC usually consists of two iron or aluminium electrodes connected to the DC power supply. When power is applied, metal will be oxidized and water will be reducing into OH^- . Together they form complexes due to their polarity they attract pollutants. Most of these complexes dissolve poorly in water and will therefore precipitate and withdraw pollutants from the waste water.

The EC reactor is the reactor that electrochemically treats the Waste water. The treatment will remove the COD and BOD particles, partly nitrogen components, Phosphates and colour. All these components will be captured in the coagulation flocs and will be removed from the water by sedimentation or floatation. 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. [1.8]

2. ELECTROCOAGULATION (EC)

THEORITICAL BACKGROUND ON EC PROCESS

An evolving alternative technology is Electrocoagulation (EC) which can be used to remove various pollutants from wastewater through in-situ generation of coagulants by electro-oxidation of the sacrificial anode, constructed mainly from iron (Fe) or aluminium (Al) metals. [1.2, 1.3, 1.5, 1.7, 2.2, 3.1]Sacrificial anode is dissolved from the anode generating corresponding metal ions, which reduce the electrostatic inter-particle repulsion causing coagulation.

By electrochemical dissolution of the sacrificial anode most of the metal ions produced are immediately hydrolysed to polymeric species these agents participate on the floc formation because they provide active surfaces for the adsorption of the polluting species and can also form bridges and entrap colloidal particles still remaining in the aqueous medium. Water is also electrolyzed in a parallel reaction, producing small bubbles of oxygen at the anode and hydrogen at the cathode. Compared with conventional chemical coagulation, electrocoagulation has many advantages such as simple equipment, easy operation and automation, a short retention time, low sludge production and no chemical requirement. Pt, TiO_2, SnO_2, Al and Fe are several materials used for the anodes, which are the most frequently used electrodes in the electrocoagulation process. For example, aluminium anodes have the same effect as the addition of Al based coagulants in conventional treatment systems. [3.2]

Aluminium electrodes are the best option with regard to the adsorption of cationic reagent species (aluminium hydroxide) on the surfaces. By using aluminium as a sacrificial electrode, EC processes have been successfully used in removal of COD. The main objective of the present work is to investigate the influencing parameters which can contribute to high removal of COD in landfill leachate by EC processes. We are studied the effect of applied voltage, initial pH and conductivity of sample on the removal of COD by EC. The removal rate has been determined in percentage. The results were discussed to determine the optimum operational conditions for COD removal. [3.2,1.5,1.8]

Table No.1

The advantages and disadvantages of EC process:

Advantages	Disadvantages
Non specific method, Address drinking water and wastewater	Need for maintenance
Combines oxidation, coagulation, and precipitation. (results in lower capital cost)	Electrode passivation Over time
Reduced need for chemical reagents, Reduced operating cost	High conductivity of the wastewater suspension is reuired
Reduced risk of secondary pollution, Low sludge production	Lack of systematic reactor design
without moving parts, low energy reuirements solar power can be used	The use of electricity may be expensive in some cases

2.1 Coagulation and Electrocoagulation

Coagulation is a phenomenon in which the charged particles in colloidal suspension are neutralized by mutual collision with counter ions and are agglomerated, followed by sedimentation. The coagulant is added in the form of suitable chemical substances. Alum [$Al_2(SO_4)_3.18H_2O$] is such a chemical substance which has been widely used for ages for wastewater treatment. The mechanism of coagulation has been the subject of continual review. It is generally accepted that coagulation is brought about primarily by the reduction of the net surface charge to a point where the colloidal particles, previously stabilized by electrostatic repulsion, can approach closely enough for Vander Waal´s forces to hold them together and allow aggregation. The reduction of the surface charge is a consequence of the decrease of the repulsive potential of the electrical double layer by the presence of an electrolyte having opposite charge. In the EC process, the coagulant is generated in situ by electrolytic oxidation of an appropriate anode material. In this process, charged ionic species - metals or otherwise - are removed from wastewater by allowing it to react with an ion having opposite charge, or with floc of metallic hydroxides generated within the effluent.

The EC technology offers an alternative to the use of metal salts or polymers and poly-electrolyte addition for breaking stable emulsions and suspensions. The technology removes metals, colloidal solids and particles, and soluble inorganic pollutants from aqueoues media by introducing highly charged polymeric metal hydroxide species. These species neutralize the electrostatic charges on suspended solids and oil droplets to facilitate agglomeration or coagulation and resultant separation from the aqueous phase. The treatment prompts the precipitation of certain metals and salts. The advantages and disadvantages of EC technology are discussed below.

2.2 Mechanism of Electrocoagulation

Water is also electrolyzed in a parallel reaction, producing small bubbles of oxygen at anode and hydrogen at the cathode. Electro coagulation, 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. Electro coagulation 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 EC mechanism for iron and aluminium anode could be represented as follow:

In the iron electrode,

Anode:

$Fe_{(s)} \rightarrow Fe^{+2}_{(aq)} + 2e^-$ ………………………… (1)

$Fe^{+2}_{(aq)} + 2OH^-_{(aq)} \rightarrow Fe(OH)_{2\,(s)}$………… (2)

Cathode: $2H_2O_{(l)} + 2e^- \rightarrow H_{2\,(g)} + 2OH^-_{(aq)}$)……….. (3)

Overall: $Fe_{(s)} + 2H_2O_{(l)} \rightarrow Fe(OH)_{2(s)} + H_{2\,(g)}$……. (4)

Due to oxidation in an electrolyte system, iron produces form of monomeric ions, Fe $(OH)_3$ and polymeric hydrox complex such as: $Fe(H_2O)_6^{3+}$,$Fe(H_20)_5^{2+}$,$Fe(H_2O)_4(OH)_2^+$,$Fe(H_2O)_8(OH)_2^{4+}$and $Fe_2(H_2O)_6(OH)_4^{4+}$ depending upon the pH of the aqueous medium.[2.2]

In the case of aluminiumelectrodes the reactions are as follows:

Anode: $Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e$………. (5)

Cathode: $3H_2O_{(l)} + 3e^- \rightarrow 3/2\,H_2 + 3H^+$……. (6)

For the aluminium electrodes, $Al^{3+}_{(aq)}$ ions will immediately undergo further spontaneous reaction to generate corresponding hydroxides and polyhydroxides. Due to hydrolysis of Al^{3+}, $Al(H_2O)_6^{3+}$, $Al(H_2O)_5OH_2^+$, $Al(H_2O)(OH)^{2+}$ generated .This hydrolysis products produced many monomeric and polymeric substance such as, $Al(OH)^{2+}$, $Al(OH)^{2+}$.[2.2]

The following Phenomena and Physiochemical reactions may also take place in the EC cell :

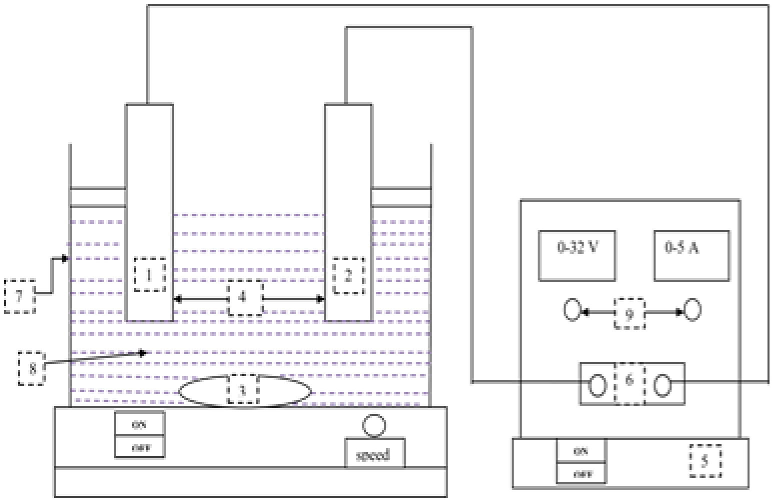

Figure 1. Schematic diagram of a two electrode electrocoagulation cell.

Table 2: - Reference table of figure:

1.	Anode electrode
2.	Cathode electrode
3.	Magnetic stirrer
4	Aluminium electrodes
5.	DC power supply
6	Output
7.	Electro coagulation call
8.	Leachate sample
9.	Controller volt & Amp.

2.3 Review of Electrocoagulation for Landfill Leachate:

2.3.1)Effect due to pH

A very important factor in the EC process is the operating pH value influencing the performance on pollutant removal. Percentage of COD removal increases when pH increases from 4 to 8.05 but decreases at pH 10. The rate of COD removal increases at the range of pH 2 to 8 but at higher values it decreases. Percentage of COD increases when current density is under 8 t0 16 mA^{-2}. Maximum color removal can been seen when pH is 6 that is 82%. The removal of turbidity can be seen maximum that is 96.6% when pH is 5.8 and cell voltage is 8 volt. This experiment works in the pH range of 3 to 7. At pH 7.73 experiments is under control and it is raw leachate and acid. This shows that how acidic pH affects the removal of heavy metals which contains leachate samples.

2.3.2)Effect due to Electrodes materials

Aluminium and iron are mostly used as electrodes because of their effectively and availability. Using Iron as anode gives better COD and NH_3-N removal as compared to using aluminium as anode. At certain time the results of COD and NH_3-N removal using iron as electrode is more than using aluminium as electrode. The settle ability of Fe $(OH)_3$ is more than Al $(OH)_3$. Therefore Fe electrode is an optimum choice.

The material of electrodes has a great effect on EC process, such as platinum (Pt), palladium (Pd), nickel (Ni), silver (Ag), copper (Cu) plates, C (rod), and stainless steel as anode were optimize for colour removal at 10 v and 120 minute of electrolysis time. Better color removal that is 70% as seen during 120 minutes using C rod, but by using Ni, Ag, Cu, Pd, Pt, and stainless steel colour removal as seen to be 5, 9, 6, 33, 46, 69% respectively.

Six Al plates with anode surface area of $108mA/cm^2$ are used as electrodes they are monopolar. Three Al plates are used as anode after 6o minutes of electrocoagulation, removal of COD as seen maximum at pH 5 that is 48% as hydrolysis of Al^{+3} depends on pH.

2.3.3)Effect due to Current Density

Current density is defined as current applied per unit surface area of the electrode. Current density is the operational parameter which is the easiest to control and determines coagulant dosage and bubble generation rates. According to Faraday's law the amount of ions released from anode increases with increasing current.

$$m = I \times t \times M / (z \times F)$$

The removal efficiency is directly proportional to current density. Energy consumption depends on time after 15 minutes of electrocoagulation the removal efficiency of 51% as seen and energy consumption of 16Kwh/m^2. The effect of removal of COD at different densities were seen by taking current density as 8, 12, 16 mA/m^2. The maximum percent of COD removal as seen at 16mA/m^2. Therefore it is best condition for electrocoagulation. Percent of COD removal increases when current density rises from 8 to 16 mA/m^2. Using low current the turbidity removal yield is maximum while using high current the yield will be minimum.

2.3.4)Effect of electrode arrangement

EC process can be affected by electrode system through electrodes arrangement and inter-electrode distance. Electrodes arrangement can either be simply composed of an anode and a cathode or be composed of many anodes and cathodes complexly settled in EC cell. The complex electrodes arrangement can be classified in monopolar and bipolar electrodes. Overall, monopolar electrodes require a low voltage and a highercurrent contrary to the bipolar electrodes that operate under a highvoltage and a lower current. It is so difficult to conclude which electrodesarrangement is better than the other considering only EC yieldgiven that it has been proved that equally BP-S could display a high ECefficiency. Taking into account the ratio effectiveness-cost,monopolar electrodes may be deemed interesting because in manycases this electrodes arrangement offers a high pollutant removal witha lower energy consumption, knowing that bipolar electrode alwaysconsumes a high energy. This last mode which is easy tohandle, needs less maintenance cost during operation, thus the impactof maintenance cost on overall operation cost should equally be consideredto choose an appropriate electrode mode.Besides the popular rectangular electrodes, there are other geometricalshapes such as circular, cylindrical. Electrodes can be settled eithervertically or horizontally in EC cell. Despite being rarely used, horizontalelectrodes in EC batch reactor may have a higher mixing efficiency.

2.3.5)Effect of inter electrode distance

The IR-drop increases as the distance between electrodes increases. Thus, energy consumption decreases with decreasing the gap between electrodes. As the distance between electrodes becomes lower, more electrochemically generated gas bubbles bring about turbulent hydrodynamics, thereby leading to a high mass transfer as well as to a high reaction rate between the coagulant species and pollutants. In addition, inter-electrode gap defines the residence time between the anode and the cathode for a continuous system and the time of treatment for a batch reactor for reaching a desirable EC efficiency. For a complex electrode arrangement, Inter-electrode distance determines also the number of
electrodes to place in electrocoagulation cell, once its volume is defined.

2.3.6)Effect of Electrolyte

The COD removal is observed over independent variables electrolyte concentration and inter-electrode distance. Electrolyte concentration was the most significant parameter affecting the COD removal. The addition of the supporting electrolyte which allows the colour and COD removal efficiency increases occurs due to the participation of active chlorine anion roles in EC reaction. Sodium chloride added to the EC system increase the conductivity and generates hypochlorite ions, which act as an oxidizing agent in the pollutant degradation.

The electrolyte duration as taken at certain time for different values of current density. To get Fe^{+2} and Al^{+3} in reactor stable pH as adjusted. At low pH promotes better conditions for metal chemical dissolving. NaCl as added to sample before each experiment. Seven electrodes as anode were optimizing for colour removal at 10 volt and 120 minutes of electrolysis. Electrical conductivity increases as e use NaCl as supporting electrolyte. As Cl concentration increases from 0.5 to 6.25gm there is increase in colour removal from 24 to 82%. During coagulation Cl will be discharged anode for production of Cl_2 and Cl_2 is further converted into ClO which can easily oxides pollutants.

3. Leachate treatment through Electrocoagulation

Author / Reference	**Electrode**	**Distance between electrode**	**experimental time**	**PH of leachate**	**Initial COD**	**Final COD**	**Curret densiy**
Rusdianasari, ahmad taqwa, jaksen, and adi syakdani(1.1)	Al & Al	1 cm	60 min	8.03 to 8.95	415 mg/l	73.77 %	30 A/m^2
N. huda, a. a. raman, and s. ramesh (1.2)	Anode & cathode	1.16 cm	60 min	7.73	-	46.05 %	1.0 A
Xiangdong li, junke song, jiandong guo, zhichao wang, qiyan feng (1.3)	Fe & Fe	10 mm	90 min	6.4 – 7.3	2566	49.8%	4.96 mA/cm^2
C.B. shivayogimath, chandrakant watawati (1.5)	Al & Al	1.5 cm	35 min	5.8	4820 mg/l	95.8%	9 V
Ghasem hassan, abdolazim alinejad, abdolmohammad sadat , abdolreza esmaeili (1.7)	Fe & Al	2 cm	90 min	8	6317 mg/l	86.9% ,	40 v
Apaydin ö, özkan e. (2.1)	Al	4 cm	5-25 min	6.5	58 kg COD/m^3	50 g COD/m^3	10–50 mA/cm2
Rabahi amel, arris sihem, (2.3)	Al	2 cm	160 min	7	5000 mg/l	61%	166.6 A/m^2
Zainab haider mussa,mohamed rozali othman, and md pauzi abdullah(2.4)	Al	2 cm	120 min	8.17	10,000 mg/l	78%	10 V
Sevil veli, tuba ozturk, anatoly dimoglo (3.0)	Al & Fe	3 mm	5 to 15min	7.71	4022.5 mg/l	L1- 73% L2- 56%	Fe anodes it is 1–10mAcm^{-2}, Al is in the range of 2–15mAcm^{-2}.
Selin top, elif sekman, sinem hoşver, m. sinan bilgili (3.1)	Al & Al	16 mm	5-30 min	6.83 - 7	6200 mg/l	45%	15.9 mA/cm^2

Rosie jotin, shaharin ibrahim, normala halimoon (3.2)	Al & Al	6.5 cm	40 min	4-8	16464.50 mg/l	65.50 %	10-12V
Mohd khairul nizam mahmad, mohd remy rozainy m.a.z., ismail abustanand norlia baharun (3.3)	Al&Stainless Steel	-	60 min	3,4,5,6,7	-	Al-88.35 % SS-72.65 %	2.5V
Fernandes,spranger,fonseca,pacheco,ciríaco,(3.4)	Al & Fe	-	-	8.05	9800 mg/l	60.5%	700mAcm^{-2}
Ghasem hassani, abdolazim alinejad, abdolmohammad sadat, abdolreza esmaeili, (4.0)	Fe & Al	0.5 to 2cm	-	7.1 to8.2	6317 Mg/lit.	86.9%	40 V
Tezcan un u. and oduncu e. (4.1)	Al	2cm	60 min	5.0	4100 Mg/lit.	1763 Mg/lit.	75Am/cm2
Shruti a byadgi, manjunath s sharanappanavar (4.2)	Al	1.5cm	45 min	7.40	-	88.25 %	10volt
Dayana donneys-victoria, nilson marriaga-cabrales (4.3)	Fe	2cm	30-50 min	5.0	10,000 Mg/lit.	<4000	8-13V
Job contreras, mario villarroel, rodrigo navia(4.4)	Al	-	15 to 65 min	6.5 to 9.5	-	88.90 %	20 to 160 Am-2

4. CONCLUSION

In many parts of engineering, the EC process is used to efficiently remove the organic or inorganic pollutants. The study investigated the removal of COD from a landfill leachate characterized by high COD concentration. Comparative tests of the performance of the electrocoagulation and chemical coagulation, vis-a-vis the evolution of pollutants, has been performed, the process efficiency is evaluated by measuring turbidity, nitrate, nitrite, phenol, and COD. Furthermore in EC and CC the procedure for elimination of the pollution is also different, so that the chemical coagulation usually leads to settling of pollution, electrocoagulation results in settling and also a flotation of pollution by micro bubble gas produced at the cathode and the anode. As a result the comparison of electrocoagulation and chemical coagulation processes used for landfill leachate effluent treatment demonstrated the practical advantage of electrochemical treatment in term effectiveness. The effect of various operational parameters such as applied voltage or current density, wastewater conductivity and initial pH was explored to determine their optimum effect on the removal efficiency. EC technology could be applied for the cost effective treatment of landfill leachate.

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