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Comparative Study on the Treatment of Landfill Leachate by Coagulation and Electrocoagulation Processes

C. Ramprasad*†, Karthik Sona*, Mohammed Afridhi*, Ram Kumar* and Naveenatha Gopalakrishnan**
*School of Civil Engineering, SASTRA University, Thanjavur, India
**Centre for Environmental Studies, Anna University, Chennai, India
†Corresponding author: C. Ramprasad

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ABSTRACT

Landfill leachate is a complex mixture of organic and inorganic compounds and their concentration level highly depends on the type of waste dumped, age of the landfill, etc. Last few decades, the researchers are exploring the feasibility of treating landfill leachate using physicochemical, biological, advanced processes and combination of these methods. The current study focused on the comparison of two commonly adopted technologies for landfill leachate treatment, chemical coagulation/flocculation and electrocoagulation process. The leachate samples were collected from two different places and examined for the following parameters: pH, turbidity, chemical oxygen demand, chlorides, alkalinity, hardness, solids and nutrients. The current study focused on studying the effect of different inorganic coagulants (alum and ferric chloride), coagulant dosages, different electrode material (titanium coated with platinum/stainless steel and aluminium/stainless steel), electrolysis time and current intensity on the removal of pollutants from leachate and reuse for non-potable applications. The raw leachates collected from the two sites were found to be significantly different in their characteristics due to the age of landfill and physiognomies of wastes dumped. The batch treatment studies showed that both the treatment systems are nearly displaying a similar kind of removal efficiency (more than 74%). Amongst that, the coagulation/flocculation process showed a better removal efficiency and cost effectiveness compared to electrocoagulation process. Additionally, the treated water was found to be not meeting the Indian Standard for inland disposal. Therefore, an additional post treatment like reed bed process or sand filtration will be a viable option for non-potable applications.

INTRODUCTION

Due to the growing population, increased living standards and mounting consumption of the packaged items paved way for the generation of solid waste. In developing countries such as India, the generated solid waste is predominantly dumped in low lying areas and much less in the sanitary landfills. The amount of waste generated by OECD countries during 2012 was 572 million tonnes of solid waste per year. The per capita generation of solid waste in the developing countries ranges from 1.1 to 3.7 kg per person per day with an average of 2.2 kg/capita/day (Othman et al. 2012). Whereas, India generates about 48 million tonnes of municipal solid waste (MSW) annually, calculated at 0.4 kg per capita per day (Kumar et al. 2017). In the year 2018, the Department of Economic Affairs (DEA) estimated that about 58 million tonnes of solid wastes is generated and disposed off in open dumps. The sanitary landfills are the widely accepted method all over the world due to its economic advantage and environmental safety (Javaheri et al. 2006, Samadi et al. 2010), but due to non-availability of stringent rules in India, the open dumping is practiced. In India from the humps of solid wastes, due to natural processes such as rain and decomposition; the solid waste produces a toxic liquid that oozes out from the hump called as leachate (Akinbile et al. 2012). The formed leachate mixes with the rainwater and contaminates the surface water and groundwater bodies, and induces potential hazard for the human health, flora, fauna and ecosystems (Aziz et al. 2004, Ramprasad & Gopalakrishnan 2013).

The leachate from the municipal solid waste dumpsite often contains varied physico-chemical characteristics depending on the waste dumped. The wastes that are dumped usually contain the organic wastes, inorganics, toxic waste, hazardous waste, biomedical waste and e-waste. Hence, the leachate from the dumpsite is categorized into hazardous and highly polluting waste by the United States Environmental Protection Agency and Central Pollution Control Board of India. The typical physico-chemical characteristics of municipal solid waste generated in India are given in Fig. 1.

The leachates are most often transported to the sewage treatment plants and treated along with municipal wastewater, leading to the failure of treatment due to the presence of hazardous chemicals leading to the toxic effect on the microbes (Bulc et al. 1997, Ramprasad & Kutty 2016). There are few other technologies like adsorption by activated carbon (Foo & Hameed 2009, Aziz et al. 2011, Deng et al. 2018), Fenton/electro-fenton (Deng & Englehardt 2006, Sruthi et al. 2018, Wang et al. 2019), biological processes like sequential batch reactor (Lin & Chang 2000, Peng et al. 2018), moving bed bioreactor (MBBR) (Chen et al. 2008, Saleem et al. 2018, Xiong et al. 2018), electrocoagulation (Li et al. 2011, Kabuk et al. 2014) and constructed wetland (Bulc 2006, Akinbile et al. 2012, Ramprasad et al. 2017). These methods involve complex and sequence of processes, and require more capital and maintenance cost. It was found by few researchers that coagulation/flocculation and electrochemical processes are simple, cost effective and efficient treatment methods for the leachates (Samadi et al. 2010, Amor et al. 2015, Zainal et al. 2017, Aziz et al. 2018).

Landfill leachate treatment by electrocoagulation and coagulation/flocculation has been studied widely in the past two decades. Ilhaan et al. (2008) studied the leachate treatment using electrocoagulation using aluminium and iron electrodes. They found 56% removal of chemical oxygen demand (COD) and 24% removal of ammonia within 30 minutes of reaction time at 631 A/sq.m. Li et al. (2011) studied the treatment of 25 year old landfill leachate using aluminium and iron electrode at 4.96 mA/sq.cm current density and 30 minutes of reaction time, which showed the maximum removal of COD (50%), ammonia (40%) and turbidity (70%). Investigation of landfill leachate treatment by electrocoagulation was carried out at different reaction times (0, 15, 30, 45 and 60 min) and current density (10, 20, 30, 40 and 50 mA/sq.cm) (Kabuk et al. 2014). The authors found that with aluminium and iron as the electrodes, the optimum current density was 30 mA/ sq.cm for a reaction time of 60 minutes. At the above optimum conditions, they obtained a removal efficiency of 60.5% for COD, 92.4% for total suspended solids, 60.8% for Total Organic Carbon (TOC) and 28.3% for Total Kjeldahl Nitrogen (TKN). Kallel et al. (2017) investigated the simplicity and effectiveness of landfill leachate treatment using aluminium-aluminium electrode with and without autoclaving. They found that after autoclaving the leachate, the removal efficiency increased significantly. At the low current intensity of 15 mA/ sq.cm with a reaction time of 2 hours, they found that the COD and nitrogen removal increased from 39% to 64% and 13% to 35% respectively, as well as the sludge production also reduced from 40% to 10%.

Similar to electrocoagulation, the landfill leachate was also treated by coagulation/flocculation process. Ferric chloride ($FeCl_3.6H_2O$) and alum are commonly used coagulants. Ferric chloride has been used to degrade landfill leachate and removal of colour from the leachate samples (Wang et al. 2002, Aziz et al. 2011). It was seen by earlier researchers that the coagulation process by ferric chloride is effective for removing high concentration of organic pollutants and suspended solids (Tatsi et al. 2003, Aziz et al. 2011, Amor et al. 2015, Li et al. 2017). The coagulation/flocculation by alum also proved to be very effective in the removal of organics, inorganics, solids and turbidity very effectively

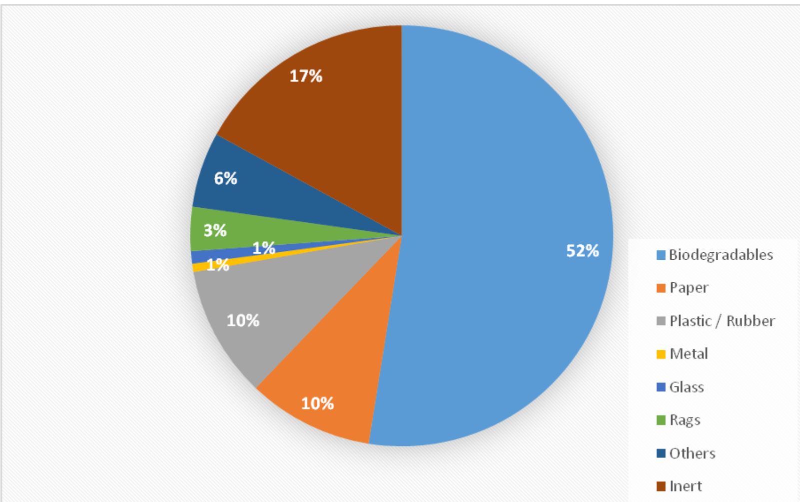

Fig. 1: Composition of the municipal solid waste.

(Maleki et al. 2009, Samadi et al. 2010, Verma & Kumar 2016, Aziz et al. 2018). It was seen from the literature survey that electrocoagulation and coagulation/flocculation are effective for the treatment of leachate. But, the landfill sites in India have varied pollutants, leading to a varied characterized leachate. There were not many studies carried out on the comparative study of landfill leachate by electrocoagulation and coagulation/flocculation processes from the Indian landfill leachate. Hence, the present study focused on the comparison of landfill leachate treatment by electrocoagulation with two different electrodes (aluminium/stainless steel (Al/SS) and titanium coated with platinum/stainless steel (Ti-Pt /SS)) and coagulation/ flocculation with two different coagulant agents (alum and ferric chloride). The scope of the study is to vary the current intensity and reaction time for the electrocoagulation process and vary the coagulants and their dosages in the coagulation process.

MATERIALS AND METHODS

Landfill leachate collection site: The landfill leachate for the study was collected from 2 different places in Tamil Nadu. The first landfill leachate was collected from Perungudi dump yard (PS), Chennai (Latitude: N 12°57'7" and Longitude: E 80°13' 49") and the second leachate sample was collected from Srinivasapuram, Thanjavur dump yard (Latitude: N 10°47'1.4" and Longitude: E 79°7'24.1"). The map showing the location of the samples collected and photographs of the landfill site are shown in Fig. 2.

Electrocoagulation: In the present study, the electrocoagulation process was carried out in the batch process. The experiments were carried out in a 500 mL borosilicate glass beaker. The working volume of the leachate used in the present study was 400 mL, and the leachate acts as an electrolytic solution. The cathode and anode were vertically positioned and parallel to each other with an electrode gap of 3 cm. The voltage difference between the electrodes was provided by a potential stat SEP 238C (Greenotronix, India), with voltage varying from 0 to 60 V and DC current varying from 0 to 6 Amperes. The positive terminal of the potential stat is connected to anode and the negative terminal is connected to cathode using copper wires. The electrodes were dipped in the electrolyte solutions. The entire setup is kept immersed in a glass bowl containing water to maintain a constant temperature, and stirred using magnetic pellets to have a uniform electrolyte concentration during the degradation process. The Fig. 3 explains the experimental setup of the electrocoagulation cell and Fig. 4 depicts the photographical view of the electrocoagulation setup. The electrochemical experiments were carried out with two different sets of electrodes, first set was stainless steel used as cathode with a dimension of 10 × 5 cm (surface area 50 sq. cm) and aluminium as low cost anode with a dimension of 10 × 5 cm (surface area 50 sq. cm), and in second set titanium coated with platinum was used as more effective anode with a surface area of 27.7 sq. cm and cathode as stainless steel.

Coagulation/flocculation: The coagulation/flocculation experiments were carried out in a batch process using the jar apparatus (Royal Scientific RSW 225C, India). The jar apparatus was equipped with six beakers of 1-L capacity and 500 mL was used as working volume. In a typical coagula-

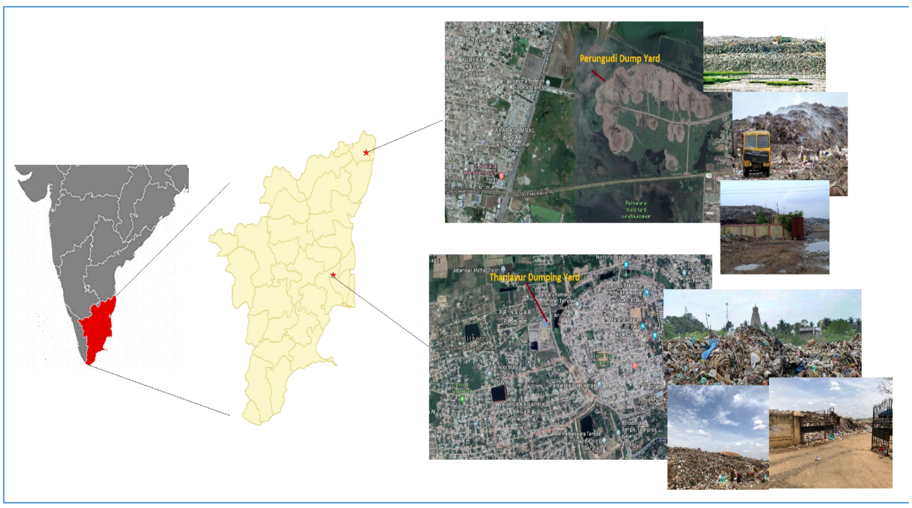

Fig. 2: GPS location showing the landfill leachate collection sites.

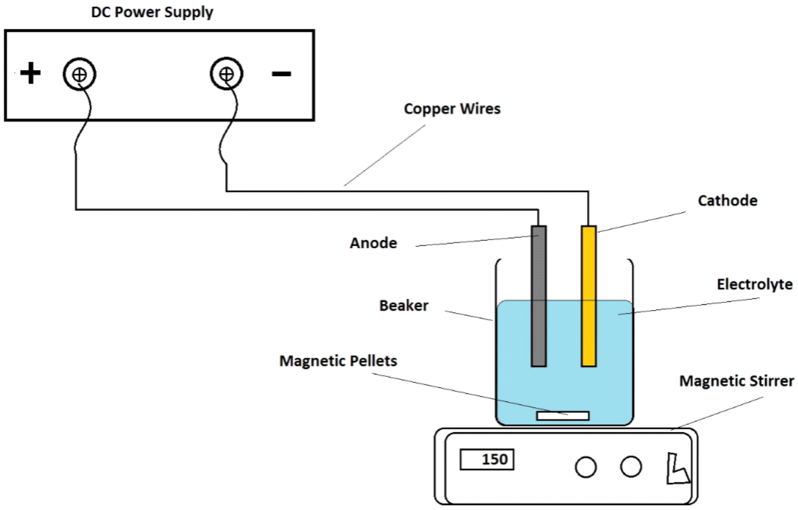

Fig. 3: Experimental setup of the batch electrocoagulation unit.

Fig. 4: Photographical view of the batch electrocoagulation

tion run, the leachate sample of 500 mL was poured into the beaker and appropriate dosages of alum ($Al_2(SO_4)_3.18H_2O$) and ferric chloride ($FeCl_3$) were added. The range of Al^{3+} used for the coagulation and flocculation process was 100-10,000 mg/L, and range of Fe^{2+} used for the study 100-1000 mg/L. The coagulants were directly added to the leachate sample of 0.5 L, and a fast stirring at 250 rpm for 5 minutes was carried out for the destabilization of suspended particles. The slow mixing at 30 rpm for 20 minutes was followed to facilitate the floc agglomeration. The sample was kept idle for a period of 30 minutes to allow the formed floc to settle. The clear sample was obtained and the supernatant was analysed for turbidity to obtain the optimum coagulant dosage. The photographs of the raw leachate sample, during coagulation process, and after the treatment are shown in Fig. 5.

Analytical method: pH and the electrical conductivity (EC) were measured using the respective probes supplied by Mettler Toledo, India. Turbidity was measured using an HF scientific 20001 Micro 100 Bench top turbidity meter (Cole Parmer, India). The solids (suspended and dissolved) were measured by gravimetric method as per standard methods (APHA) 2540. The chlorides (APHA 4500), total alkalinity (APHA 2320) and total hardness (APHA 2340) were evaluated by titrimetric method as prescribed by standard operating manual (APHA 2012). The chemical oxygen demand (COD) was determined by the closed reflux method as prescribed in the APHA 5220. The nutrients (ammonium and nitrate) and sulphate were measured colourimetrically using UV-Vis spectrophotometer (Bio-Equip, China) as per the procedure prescribed by APHA 4500 (APHA 2012).

Statistical analysis: In order to compare the treatment performance of the electrocoagulation system and the coagulation/flocculation system, a discriminant function analysis has been performed. One-way ANOVA test at 95% confidence interval was applied to the removal efficiency during the monitoring period for the significant parameters like COD, turbidity, chlorides, pH and solids. The analysis was performed using IBM SPSS 16 software at a significance level of $p < 0.05$.

RESULTS AND DISCUSSION

Raw Landfill Leachate Characteristics

The landfill leachate samples were collected from two different sample locations as shown in Fig. 2, having similar

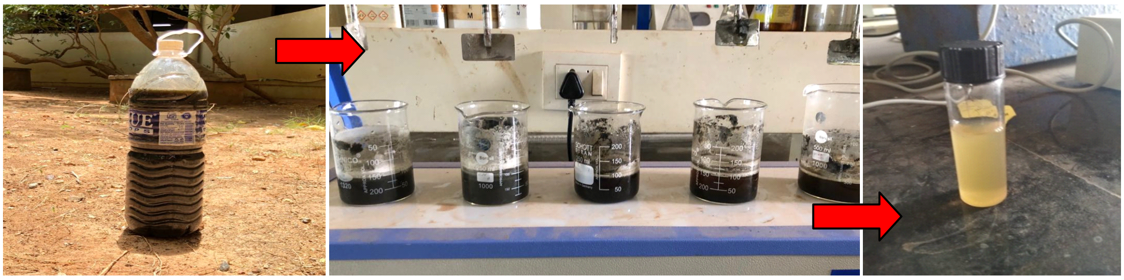

Fig. 5: Photographical view of the batch coagulation/flocculation process.

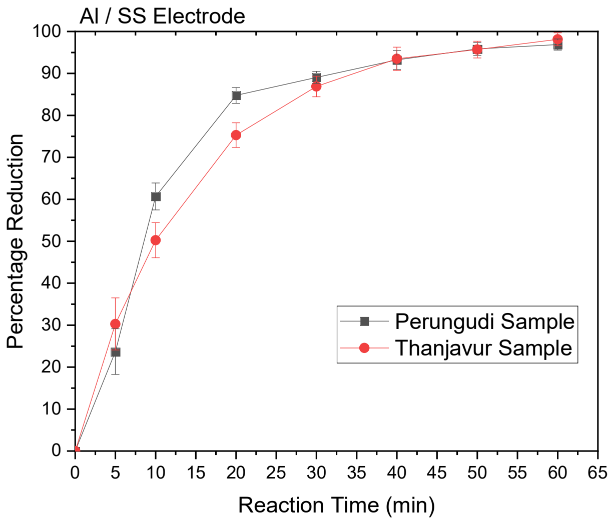

Fig. 6: Effect of Al/SS electrode material on turbidity removal.

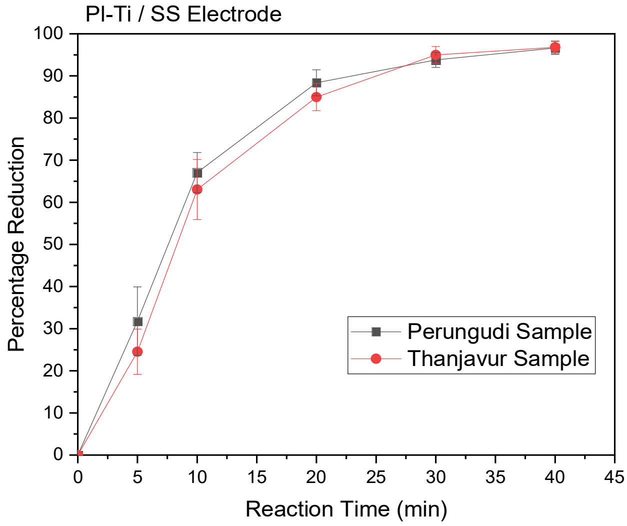

Fig. 7: Effect of Ti-Pt/SS electrode material on turbidity removal.

topography, climate and waste characteristics. It was found that the leachate from the Thanjavur dump site (TS) was much stronger compared to the leachate collected from the Perungudi dump site (PS) as seen in Table 1. The pH value for the TS sample was in the range of 5.82 to 7.85, and PS sample was in the range of 6.06 to 7.35. The obtained pH was in good agreement with the earlier researchers Foo & Hameed (2009), Aderemi et al. (2011) and Tong et al. (2015). The pH value of the landfill leachate reaches the acidic nature due to the characteristics of the solid waste and the age of landfill. The pH for the mature landfill is in the range of 6.6-7.5, and for younger landfill in the range of 4.5-7.5 (Aziz et al. 2011). Few researchers also state that the acidic nature of the leachate is mainly due to the organic wastes such as foods, vegetables, fruits and humus substances (Aderemi et al. 2011, Tong et al. 2015). In the obtained leachate samples, pH was in the range of 5.5-9.0 prescribed by the Central Pollution Control Board (India) for inland discharges. The electrical conductivity (EC) value for the TS sample was 8120-9550 µS/ cm, and for the PS sample 7830-8250 µS/cm. The obtained results were confirmed by the earlier values obtained by Bashier et al. (2010) and Ziyang et al. (2009) which were 6380-25060 µS/ cm. The turbidity of the Perungudi sample (PS) was in the range of 256-885 NTU, and of the Thanjavur sample (TS) in the range of 671-1630 NTU. The significant variations in the turbidity values in the individual samples may be attributed to the seasonal variations.

The suspended solids (SS) concentration was found to be more in the TS sample (2220-5100 mg/L) compared to the PS sample (680-1800 mg/L) due to the waste characteristics and age of the landfill (TS is the youngest of the two). It was earlier proved by the researchers that the typical suspended solids concentration of the mature landfill was in the range of 100-400 mg/L (Aziz et al. 2011). Additionally, the leachate SS concentration for a landfill leachate varies from 2-1,40,900 mg/L and highly depends on the age of the landfill (younger landfill have more suspended solids) (Foo & Hameed 2009). The concentration of chlorides and sul-

Table 1: Raw landfill leachate characteristics.

Sl. No	Parameters	Units	Perungudi Sample (PS)	Thanjavur Sample (TS)	CPCB Disposal standard value (Inland surface discharge)
1.	pH	NA	6.06-7.35	5.82-7.65	5.5-9.0
2.	Electrical conductivity (EC)	µS/cm	7830-8250	8120-9550	500
3.	Turbidity	NTU	256-885	671-1630	< 50
4.	Dissolved Oxygen	mg/L	0.33-0.74	0.22-0.57	NA
5.	Chemical oxygen demand (COD)	mg/L	3400-5400	2400-3800	250
6.	Total suspended solids	mg/L	680-1800	2220-5100	100
7.	Total dissolved solids	mg/L	17,280-21,350	22,840-26,900	2100
8.	Total solids	mg/L	19,960-24,550	25,060-32,000	2200
9.	Total Alkalinity	mg/L	NA	6400-9500	NA
10.	Total Hardness	mg/L	NA	2100-4200	NA
11.	Chlorides	mg/L	3505-7667	2334-5727	1000
12.	Sulphate	mg/L	188-277	NA	NA
13.	Ammonia-Nitrogen	mg/L	950-1200	NA	50
14.	Nitrate-Nitrogen	mg/L	84-177	NA	10

NA - Not Applicable; mg/L - milli gram per liter; NTU - Nephelometric Turbidity Unit; µS/ cm - Micro Siemens per centimeter

phates in the present study was found to be 3505-7667 mg/L and 188-277 mg/L respectively for PS sample. The chloride concentration of the TS sample was 2334-5727 mg/L. The concentration of the chlorides and sulphates was higher for the Perungudi sample than Thanjavur sample, which may be attributed to the seawater intrusion and higher industrial effluents being dumped in the Perungudi site. The values obtained in the present study were much lesser than the values obtained by Zhang et al. (2013) and El-Salam et al. (2015) with the concentration of chloride and sulphate ranging from 9500-16,250 mg/L and 298-720 mg/L respectively. The dissolved oxygen (DO) level of the samples was near to anaerobic nature with Perungudi sample DO range from 0.33-0.74 mg/L, and Thanjavur sample range from 0.22-0.57 mg/L.

The chemical oxygen demand (COD) for the Perungudi and Thanjavur leachate samples was in the range of 3400-5400 mg/L and 2400-3800 mg/L, respectively. The COD values in the present study indicate that leachate in the PS and TS landfill can be classified to be in the methanogenic phase. According to Kostova (2006), the present COD values of the leachate are within the range for methane fermentation phase. The COD values recorded by Jokela et al. (2002) and Aziz et al. (2011) agree with the present COD values. The difference in the COD values between the samples may be due to the solid waste composition, climatic conditions, and landfill age (Christensen et al. 2001, Aziz et al. 2011). Typically, the toxicology effects of the COD (the non-biodegradable components) in the landfill leachate into the environment were comprehensively explained by Renou et al. (2008) and Aziz et al. (2011). Therefore, the leachate before discharged into the environment has to be treated to be within the Indian CPCB prescribed level of 250 mg/L.

The concentrations of ammonia-nitrogen and nitrate-nitrogen for the leachate at Perungudi landfill were 950-1200 mg/L and 84-177 mg/L respectively. The obtained values are in good agreement with Aziz et al. (2011). The higher levels of ammonia-N in the landfill leachate are one of the most critical problems in the longer operation of the landfill (Aziz et al. 2004, Bashir et al. 2010). The untreated ammonia in the leachate leads to algal growth, eutrophication, depletion of oxygen and increased toxicity to living organisms in the water bodies (Aziz et al. 2011). Therefore, the leachate before discharged into the inland surfaces has to be treated meeting the standard limits (Ammonia-N: 50 mg/L and Nitrate-N: 10 mg/L) as prescribed by the Central Pollution Control Board. It was observed that irrespective of the age of landfill, the characteristics of waste and spatial-temporal variations, there is a statistically significant difference in the mean concentrations between the two sites of the independent parameters like COD, turbidity, suspended solids, chlorides and pH, the significance level is 0.0074 (p = .0074), which is below 95% ($p<0.05$) confidence limit.

Electrocoagulation

In the electrocoagulation process, the electrolysis time and current intensity (A/sq. dm) are the most important operational parameters setting the ultimate removal. Some investigators also showed that the choice of electrode material also plays a vital role in the removal of the pollutants (Ilhaan et al. 2008, Kallel et al. 2017, Aziz et al. 2018).

Effect of electrode material: In the electrocoagulation process, the electrode material plays a vital role in the degradation of the pollutants. The researchers have proved that the treatment efficiency has improved if a proper cathode and anode material is chosen (Li et al. 2011). Based on the literature survey, the most widely used and cost effective electrodes (aluminium and stainless steel) and most efficient in treating leachate (titanium-platinum and stainless steel) were employed for electrolysis (Zaied & Bellakhal 2009, Li et al. 2011). In the current study, the leachate samples from the two sites (Thanjavur and Perungudi) were treated using different electrodes (Al/SS and Ti-Pt/SS) at a current intensity of 2.95 A/sq. dm at a specified time interval (5, 10, 20, 30, 40, 50, 60 min). As seen from Figs. 6 and 7, the removal efficiency between the two samples do not have much variations. The statistical analysis also proved that there is no statistically significant difference ($p<0.05$, $p = 0.0034$) between the removal efficiencies. It was observed from Figs. 6 and 7 that the Ti-Pt / SS electrode showed a better performance than the Al/SS electrode with attaining a maximum removal efficiency of 97.4% within 40 minutes of reaction time. The aluminium/stainless steel electrodes showed a maximum removal efficiency (96.3%) after a reaction time of 60 minutes. Similar results were obtained by Li et al. (2011) for the leachate treatment using aluminium/stainless steel with an electrolysis time of 50 minutes.

In the electrochemical process, the positively charged ions are attracted towards the negatively charged hydroxyl ions producing ionic hydroxides. Hence, the turbidity or suspended particles in the leachate tend to get agglomerated by the coagulation process. The pair of electrodes (cathode and anode) are arranged opposite to each other and immersed in the leachate. The cathode (stainless steel) emits the electrons which neutralize particles in the wastewater by forming hydroxide complexes which agglomerates (Ukiwe et al. 2014). The electrode such as aluminium or iron initiate the coagulation process and the metal ions dissolve at the cathode and anode according to the following equations:

At Anode:

$$Fe_{(s)} \rightarrow Fe^{n+}_{(aq)} + ne^{-} \quad ...(1)$$

$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^{-} \quad ...(2)$$

At Cathode:

$$2H_2O_{(s)} + 2e^{-} \rightarrow H_2 + 2OH^{-} \quad ...(3)$$

Meanwhile, if the anode potential is sufficiently higher, secondary reactions may also occur, such as direct oxidation of organic compounds and of Cl^{-} ions present in the leachate (Kobya et al. 2003). The chloride produced is a strong oxidant and can oxidize some organic compounds present in the leachate, as seen in the following equation,

$$2Cl^{-} \rightarrow Cl_2 + 2e^{-} \quad ...(4)$$

Effect of electrolysis time: As the literature suggests, the electrolysis time also had an impact in the electrocoagulation process. In order to explore the effect of operating time, the current intensity is held at a constant rate of 2.95 A/sq. dm. The treated samples were taken at specified time intervals of 0, 5, 10, 20, 30, 40, 50, 60 minutes and analysed for the turbidity. As it can be seen in Figs. 8 and 9, an increase in the reaction time from 5 min to 60 min, the turbidity level also getting removed. It was also observed that the removal of suspended particles was much faster in the Ti-Pt/ SS electrode than Al/SS electrode. Within 40 minutes (Ti-Pt /SS) and 60 minutes (Al/SS) of reaction time, an optimum removal was attained, there is no significant further change in the turbidity level. Similar kind of results were obtained by earlier researchers (Kobya et al. 2003, Li et al. 2011). As the electrolysis time increases, the rate of bubble generation also increases, and the increase of concentration of hydroxide flocs leads to higher coagulation, flotation and settling. It was also seen in Figs. 8 and 9 that the turbidity levels in both the samples, TS and PS are meeting the CPCB discharge standard limits (<50 NTU) at the optimum reaction time.

Effect of current intensity: It was earlier reported that in the electrocoagulation process, the current intensity has a major impact on the treatment efficiency. An additional experimental study was performed to determine the effects of operational conditions on turbidity removal efficiency by changing the current intensity. The current intensity was varied from 1.4, 1.65, 1.8, 2.05, 2.2, 2.45, 2.7, 2.95 and 3.2 A/sq. dm through an optimum reaction time for the various sets of electrodes. It was seen that as the current intensity increases the turbidity level started to decrease and reached a stationary phase (Figs. 10 and 11). For the Al/SS electrode combination, the optimum current intensity was found to be 2.95 A/sq. dm with a reaction time of 60 minutes. The results are in good agreement with Ilhan et al. (2008). In case of Ti-Pt/ SS electrode combination, the optimum current intensity was found to be 2.2 A/sq. dm with a reaction time of 60 minutes. The treatment efficiency has increased with the increase in the current intensity; at higher current intensity the aluminium gets oxidized leading to more hydroxide formation. The formed hydroxide ions get agglomerated and precipitated by removing the organic contaminants (Bouhezila et al. 2011).

Coagulation/flocculation

In the recent decades, the coagulation/flocculation has been extensively studied for the treatment of various types of

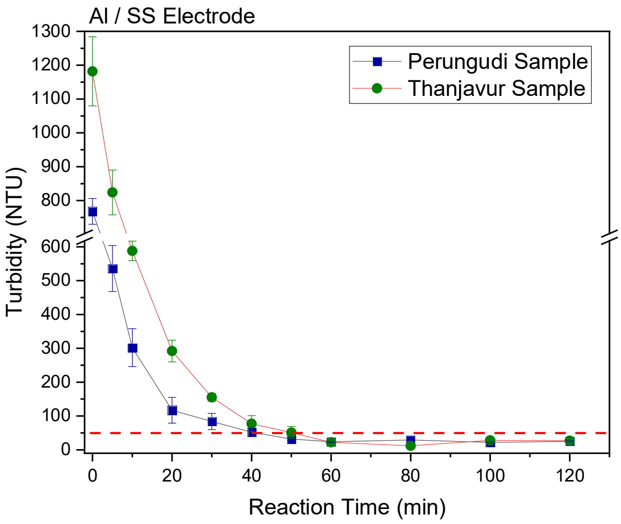

Fig. 8: Effect of electrolysis time on turbidity removal for Al/SS electrode.

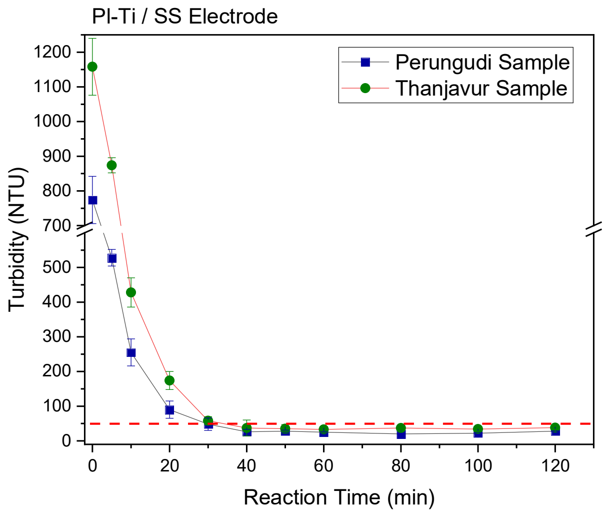

Fig. 9: Effect of electrolysis time on turbidity removal for Ti-Pt/SS electrode.

wastewater including domestic wastewater, greywater, textile wastewater, leachate, etc. (Tatsi et al. 2003, Joo et al. 2007, Gupta et al. 2012, Teh et al. 2016). Most of the suspended and settleable materials present in the wastewater get agglomerated by the ions generated by the coagulants and get settled. The disadvantage of EC process is that it requires power and produces high amount of toxic sludge; while coagulation is highly effective, simple and produces comparatively less sludge.

Effect of inorganic coagulants: Amongst the inorganic coagulants used for the treatment of leachate, alum and ferric chloride were found to be very effective in removing the suspended, settleable solids, organics and nutrients from the leachate. It was reported that alum was found to be more effective in suspended solids removal (up to 99%) with an alum dosage in the range of 100-1000 mg/L (Aziz et al. 2011, Bouhezila et al. 2011). Whereas, few other researchers show that the ferric chloride has a better removal efficiency than alum in the removal of organics, solids, colour and turbidity (Song et al. 2004, Sarkar et al. 2006). Therefore, in the present study, the effect of both the coagulants was checked for their treatment efficiency. It can be seen in Figs. 12 and 13, that the turbidity level decreased with an increase in the coagulant dose until an optimum level is attained. After the optimum level, further increase in the coagulant dosage leads to the increase in the turbidity level of the leachate. The reason for this could be the restabilization of the colloidal particles as the dosage of the coagulants is in excess of the optimum value. The findings are in good agreement with the results obtained by Aziz et al. (2011).

It was observed that ferric chloride shows better performance in removing the turbidity from leachate with lower dosage compared to alum (Figs. 12 and 13). For the Perungudi sample, the turbidity level reached a minimum of 35 NTU at an alum dose of 700 mg/L, while for the Thanjavur sample the minimum level of turbidity (82 NTU) was obtained at an optimum dose of 1500 mg/L. Maleki et al. (2009), showed that COD and suspended solids reduction was maximum when the alum dosage was in the range of 0.8-1.5 g/L. At an optimum dosage of 500-700 mg/L of ferric chloride, the turbidity level reached a minimum of 47 NTU and 45 NTU for Perungudi and Thanjavur landfill leachate samples. The reason for better performance of the ferric chloride than the alum is that, at elevated pH the hydrous iron hydroxides precipitate in greater extent than alum flocs (Tong et al. 2015). It was noted that after the addition of coagulants, the pH level of the leachate started to increase up to 8.5-9. It was proved by researchers that hydrolysis of alum and ferric chloride and formation of positively charged gels (mononuclear and polynuclear) of corresponding hydroxides happen at alkaline medium (Zhu et al. 2011). The formed positive species combine with colloidal particles (negatively charged) present in the leachate by charge neutralization and sweep settling precedes with precipitating out the settled and suspended particles (Maleki et al. 2009, Bouhezila et al. 2011, Teh et al. 2016). The overall removal efficiency of the treatment systems after the optimum conditions are provided in Fig. 14.

Cost Analysis

Apart from the treatment efficiency, the most important pa-

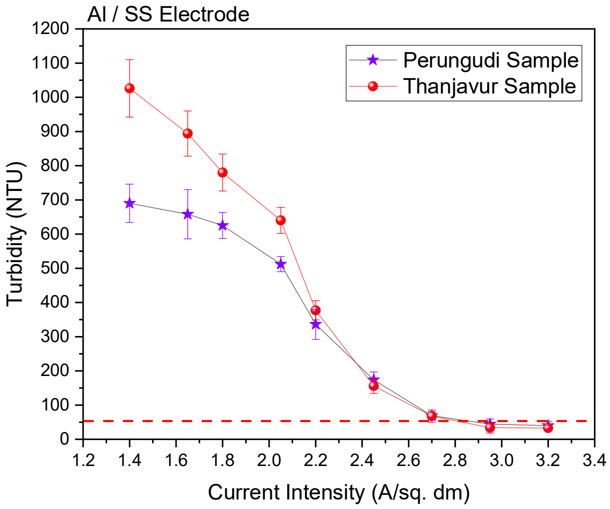

Fig. 10: Effect of current intensity on turbidity removal for Al/SS electrode.

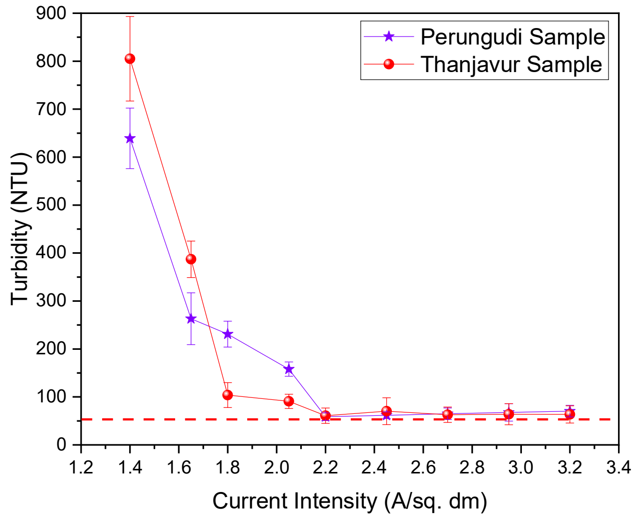

Fig. 11: Effect of current intensity on turbidity removal for Ti-Pt/SS electrode.

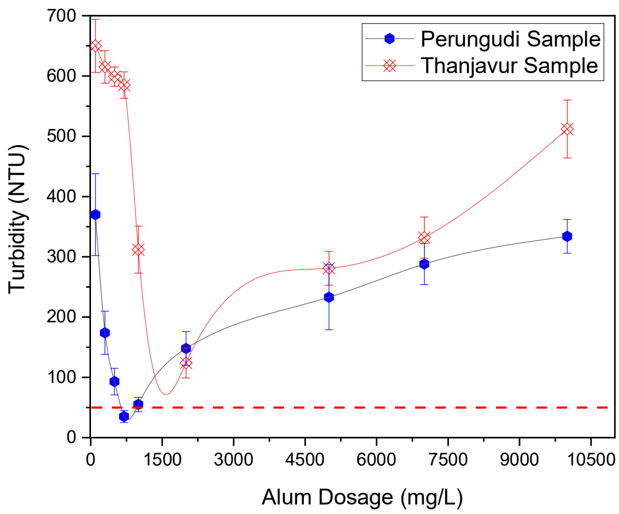

Fig. 12: Effect of alum dosage on turbidity removal.

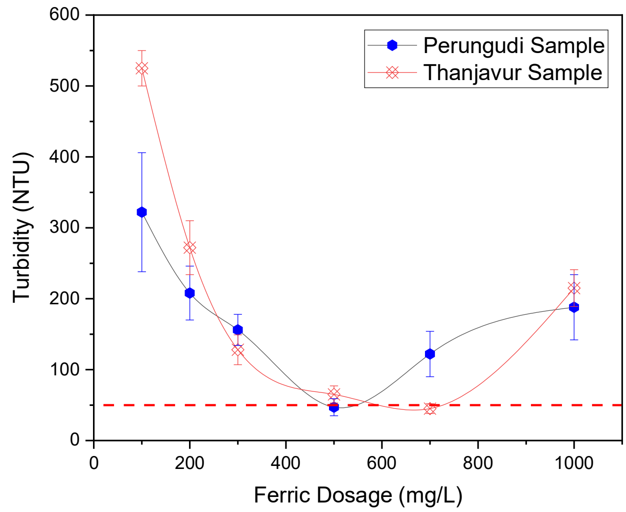

Fig. 13: Effect of ferric chloride dosage on turbidity removal.

rameter that decides the accomplishment of the treatment method is the economic feasibility of the treatment. In the current study, the consumption of chemicals, electrode cost, energy consumption and sludge disposal costs were evaluated. In the coagulation process, the ferric chloride and alum cost was found to be 6.14 USD/cu.m and 13.69 USD/ cu.m for the optimum dosage. In the electrocoagulation process, the electrode cost and the energy consumption plays a vital role. The cost of aluminium electrode was 1.57 USD/kg, and cost of iron electrode 0.24 USD/kg as per Indian market price in 2012. The Ti-Pt coated electrode was found to be slightly costlier compared to the other electrodes (138.7 USD/sq. m). The electrical energy was calculated by the following Eq. (5) provided by Bouhezila et al. (2011).

$$E = UIT \quad ...(5)$$

Where, 'E' is the electrical energy consumed in kWh per unit volume of leachate treated, 'U' is the cell voltage in Volt, 'I' is the current in Ampere and 'T' is the time taken in hours for the treatment. The energy consumption by the aluminium/stainless steel was found to be 0.323 kWh, and by Ti-Pt electrode to be 0.134 kWh. As per Indian market price in 2012, per unit of energy cost was 0.42 USD. Therefore, the electrochemical treatment cost per cu.m volume of leachate was found to be 339 USD (Al/SS electrode) and 141 USD (Ti-Pt/SS electrode). The sludge transportation, dewatering and disposal were evaluated to be 0.03 USD/kg for each of the processes. It is clear from the cost analysis that the coagulation/flocculation will be a viable option for the treatment of leachate. Furthermore, to increase the removal efficiency and cost effectiveness, a simple sand fil-

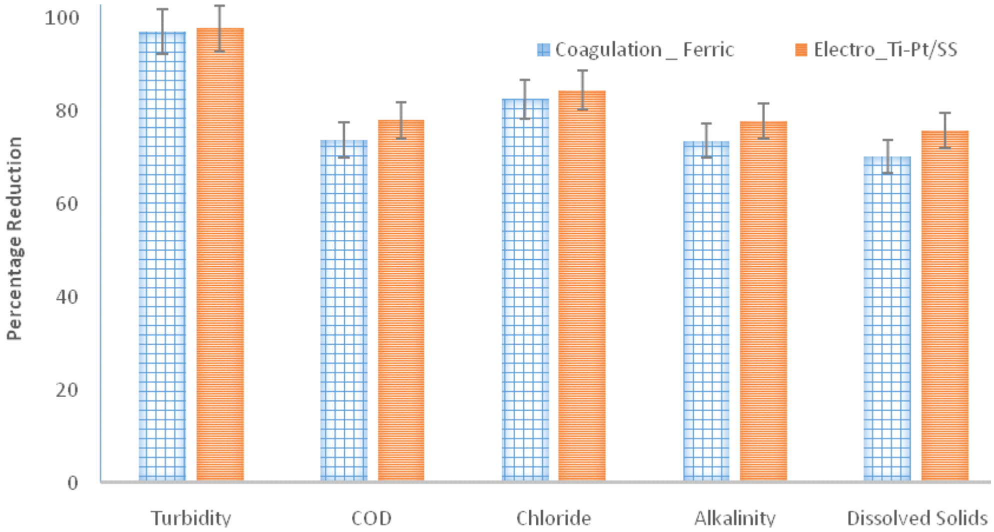

Fig. 14: Overall removal efficiency of the different treatment processes after the optimum conditions.

tration or reed bed filtration as a post treatment will be an effective solution for the treatment of leachate and reuse for secondary applications.

CONCLUSION

The present study showed the feasibility and comparison of electrocoagulation and conventional chemical coagulation methods for the treatment of sanitary landfill leachate. The leachate samples from two different locations were collected and found that the raw leachate characteristics were significantly different. The influence of electrode material, electrolysis time, current intensity and inorganic coagulant dosages on the removal of turbidity, solids, pH, COD and chlorides has been studied. It was found that the optimum current intensity for a reaction time of 60 min was found to be 2.95 A/sq.dm and 2.2 A/sq.dm for Al/SS and Ti-Pt/SS electrode respectively. In case of chemical coagulation process, an optimum dosage of ferric chloride and alum as 500-700 mg/L and 1500 mg/L respectively was achieved showing a maximum percentage removal of turbidity. The better performance in the electrocoagulation was obtained for titanium coated with platinum/stainless steel electrode with a removal efficiency of turbidity, chemical oxygen demand, chloride, alkalinity and dissolved solids to the extent of 98%, 78.1%, 84.5%, 77.9% and 75.8% respectively. Whereas, for the coagulation/flocculation process, the better removal of pollutants was seen in ferric chloride with the corresponding removal efficiencies of 97%, 74%, 83%, 74% and 71% for turbidity, chemical oxygen demand, chloride, alkalinity and dissolved solids respectively. Overall, both the treatment systems showed almost similar level of removal for leachate collected from two different locations, and among them, coagulation/flocculation was found to be cost effective than electrocoagulation process. Additionally, it was also noted that the treated water is not meeting the Indian inland disposal standard, therefore an additional post treatment like reed bed system or filtration system is needed.

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