Journal of Emerging Technologies and Industrial Applications
Vol. 4 No. 2 (2025) pp. 1-6
e-ISSN: 2948-507X

Journal homepage: https://jetia.mbot.org.my/index.php/jetia/index

Development of Leachate Treatment System Prototype Integrating Electrocoagulation and Membrane Bioreactor

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Abstract: Membrane bioreactor (MBR) is a technology that combines biological- activated sludge process and advanced membrane filtration. Electrocoagulation (EC) is an electrochemical technique that is extensively applied to treat landfill leachate. EC can be as a pre-treatment unit prior to the MBR in a waste water treatment process that greatly improved the treatment efficiency. In this study, the goal is to develop a leachate treatment system prototype integrating electrocoagulation and membrane bioreactor. The inlet leachate characteristics such as BOD, COD, TSS, NH3–N concentration along with the color of the leachate were fixed as the inlet of the treatment system prototype. The design parameters are used to calculate the dimensions and design of every unit of the system in order to achieve the desired treatment efficiency. The requirements of the systems are defined in details and the detailed drawings of each of the treatment units of the treatment system are portrayed. A labelled drawing of the whole system is also created to visualize the prototype in great details.

Received 15 June 2025; Accepted 21 September 2025; Available online 28 December 2025

Keywords: electrocoagulation, membrane bioreactor, landfill leachate, chemical oxygen demand, ammonia

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1. Introduction

A landfill site is a site for the disposal of waste materials. Landfill method has been the oldest and most common form of municipal solid waste disposal due to lower operation and maintenance cost. However, the aftermath of this method is the production of a type of liquid called leachate. The generation of this liquid has considerable potential to cause many environmental problems including the contamination of surface and ground water. Landfill is the method used in Malaysia too as it is cheaper to dispose the wastes than to recycle it. As such, the treatment of landfill leachate has been a very important issue.

Landfill leachate is a contaminated liquid effluent with intensively dark colour generated as the result of rainwater percolation through the waste in landfill site, the biochemical processes in waste's cells and the inherent water content of the wastes [1]. The contents of the leachates include high concentration of both biodegradable and non- biodegradable organic matter or otherwise known as refractory organic matter [2]. It often contains heavy metals, ammonium and many soluble and insoluble compound [3]. Nevertheless, the characteristics of leachate vary upon the nature conditions such as moisture content, pH, temperature, local precipitation pattern, oxygen level and landfill operation [4]. These leachate characteristics are highly variable depending on several aspects including waste composition, site hydrology, waste compaction, amount of precipitation, cover design, sampling procedures, the interaction of leachate with the environment, landfill design and operation [5][6][7]. As such, these characteristics are best quantified as Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), pH, ammonium nitrogen (NH_3 - N), turbidity, heavy metal content to make the identification of the suitable treatment method of the leachate.

Landfill leachates composition is greatly influenced by its age [5]. Young leachate is prominently known with the high amount of volatile acids, as a results of acid phase of fermentation. Mature landfill, on the other hand, contains greater portion of humic acid and fulvic acid, which are believed to be the cause of its intensively dark colour [7]. These pollutants in the leachate have different effects on the environment if the discharge is not treated properly. The form of nitrogen in landfill leachate exists in mainly organic nitrogen and ammonia nitrogen [8]. The high concentration of ammonia nitrogen (NH_3–N) in the landfill leachate is the culprit of eutrophication of surface water. When the untreated leachate is discharged into soil, it can contaminate the surface water in nearby water sources such as lake and river. The depletion of dissolved oxygen in surface water happens when ammonia is biologically oxidized to nitrite in the presence of oxygen [9]. Eutrophication is not the only consequence of the high concentration ammonia nitrogen in the leachate, it also contributes to the loss of aquatic lives and the concerns of public health [10].

Humic substances (humic acid and fulvic acid) are the major contaminants in landfill leachate, accounting for about 70% of COD in it [11]. Humic substances gives the foul taste and coloration to the aquatic environment once the landfill leachate enters the surface water and ground water [12]. Various techniques are present to be used for colour removal of landfill leachate namely chemical precipitation, adsorption through granular activated carbon, nanofiltration, ozonation, radiation, UV photolysis, chemical coagulation, biological treatment with various additives, anaerobic process, fluidized biofilm process and advanced oxidation with UV/H_2O. However, these conventional treatments are ineffective and expensive to treat leachate [13],[14].

It is suggested that coagulation followed by flocculation process is an effective way to remove the high concentration of organic pollutants. This leads to an advanced coagulation method other than the conventional chemical coagulation which is electrocoagulation (EC). In EC, the coagulating agents such as alum or ferric chloride and other additives like polyelectrolytes are not needed throughout the process. A device named "Electro Coagulator" dissolves aluminium electrode (anode) electrochemically into the electrolyte and produces hydroxyl ions at the cathode to form aluminium hydroxide. The hydroxide purifies the water by flocculates and coagulates the suspended solids. An EC reactor comprises an electrolytic cell with two electrodes [15], with one of them being anode and the another being cathode. The electrode is made up of conductive metal plates and most commonly, aluminium and iron are used as the material for the electrodes. Coagulant in situ is produced in the form of insoluble pH that is able to remove a great variety of pollutants when electricity is channelled through the electrodes [16]. The metal hydroxide produce is capable of neutralizing the electrostatic charge on the suspended solids, particulate matters and oil droplets to aid in coagulation and agglomeration. Eventually, by sedimentation or electroflotation, the coagulated particles can be separated from the liquid [17].

Membrane bioreactor (MBR) is a biological wastewater treatment process with the application of membrane technology. Compared with conventional activated sludge system, MBR system has better effluent quality, process stability, smaller footprint, increased biomass or mixed liquor suspended solids (MLSS) retention and low sludge production according to Van Dijk and Roncken (1997) [18]. MBR has two functional units, namely the biological unit which is also known as bioreactor that takes care of the biodegradation of pollutants and the conventional activated sludge system makes use of gravitational settling of microbial flocs for solid-liquid separation only. Due to the presence of refractory compounds in the landfill leachate, biological system does not provide the necessary quality of the treated water as the refractory compounds cannot be treated effectively by MBR [19]. For instance, the humic substances aforementioned are difficult to be oxidized biologically. As such, integrating EC into MBR is a promising technique in order to improve the quality of the treated water. Both MBR and EC are reported as a good alternative to treat wastewater effectively. The incorporation of EC into MBR would give a promising result as the leachate will be treated by combining electrochemical, biological and membrane process in a single unit while improving the membrane performance [20].

2. Methodology

2.1 Overall Design Procedures

The prototype was based on 1 m^3/day flow rate and the following raw leachate properties as shown in Table 1. The targeted quality of the discharged leachate was based on the standard discharge limit of the Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009 (PU(A) 433). Based on these inputs, the design parameters are calculated using several relevant equations. The software AutoCAD is used as the CAD software in producing the detailed drawings of each of the components in the leachate treatment system. 3D illustration is first drawn, then the 2D flat-shots are generated in different views to provide a clear illustration of the components of the treatment system. Dimensions

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are labelled with the unit of millimetres (mm) for each and every part of the components as well.

Table 1 - Leachate Properties as Design Parameters for the Prototype and the standard of discharge

Properties	Unit	Value	Standards
pH	-	7.2	
COD	mg/L	16848.3	400
BOD	mg/L	1572.0	20
TSS	mg/L	1542.5	50
NH3-N	mg/L	1737.3	5
Colour	PtCo	2794.0	100

2.2 Determination of Desired Removal Concentration for Each Tank

The desired removal concentrations were based on the removal concentrations reported in the previous theses. For instance, the desired removal concentration for EC was based on the removal concentration reported by Wong [21]. For the case where the reported removal concentrations were not sufficient to comply with the discharge standard, the values of the desired removal concentrations were adjusted in a way that the overall system can treat the leachate according to the regulation.

2.3 Electrocoagulation System Design Procedure

In order to achieve similar removal concentration with Wong [21], the same charge loading and residence time were used. For the prototype, the default volumetric flow rate (Q) was 1 m^3/day or 0.69 L/min. Volume ratio between reaction zone and sedimentation zone; and Length: Width: Height ratio of each zone were based on the same ratios used by Wong [21]. Based on Wong [21]'s EC design, the height of the hydraulic zone was 73% from the total height of the EC tank [21] The same percentage value was used to calculate to total height of the EC tank of the prototype, thus the total EC tank volume. The ratio of effective surface area of the electrodes to the volume of the reaction zone is maintained based on the ratio used by Wong [21]which is 0.016 mm^2/mm^3. The total current supplied required to maintain the same charge loading with the 1 m^3/day flow rate is 54 A. Therefore, the current density of the prototype can be calculated.

2.4 Three-zone System Design Procedure

For aerobic zone, the procedure was based on the activated sludge design procedure. Based on Audrey [22], the highest removal of BOD_5 (96% or 397 mg/L) was achieved by using F/M ratio of 0.11 and MLVSS of 7780 mg/L. In comparison, Robinson and Maris [23] recommended F/M ratio of 0.21 kg BOD kg^{-1} MLVSS day^{-1} or less and mixed liquor volatile suspended solids (MLVSS) of 1450 mg/L. This can achieve high removal of BOD (>;98%) and COD (>;92%) for treating a medium-strength leachate from domestic solid wastes in a landfill (COD 5000 mg/L, BOD 3000 mg/L).

For anoxic and anaerobic zone, there is not physical boundary separating in the proposed three- zone biological membrane system tank. Therefore, there is no clear-cut separation between the zones. The volume of both the anoxic and anaerobic zone is proposed to be the same as the volume of the aerobic zone which adds up to yield the total volume of the tank as the three times of the volume of the calculated aerobic zone.

2.5 Bleaching System Design Procedure

The volume of bleaching is estimated by estimating the chlorine contact time first:

$$Contact\ time = \frac{K}{chlorine\ residual} \quad (1)$$

$$Volume = flowrate \times contact\ time \quad (2)$$

Subsequently, the volume as well as the dimensions of the bleaching tank can estimated.

Table 2 - K Values in Different Temperature and pH

pH	Lowest Water Temperature (°F)		
	>50	45	40
6.5	4	5	6
7.0	8	10	12
7.5	12	15	18
8.0	16	20	24
8.5	20	25	30
9.0	24	30	36

3. Results and Discussions

3.1 Desired Removal Efficiency for Individual Tank

The removal concentrations of several aspects are according to the previous studies of Taib [24], Wong [21], Audrey [22] and Kuy [25]. The removal concentration of BOD as well as NH_3-N in the three-zone biological tank is assumed to be the desired removal concentration in order to obtain the desired dimensions for the tank in order to carry out the removal of wastes at that concentration. The same assumption is made on the removal of colour at bleaching tank. The mass balance for the system is shown in Fig. 1.

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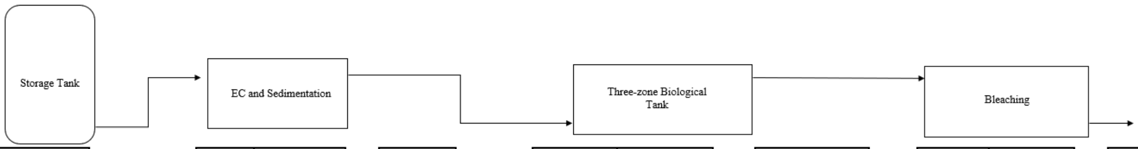

Parameter	Initial Concentration (mg/L)	Eff	Concentration of Removal (mg/L)	Outlet Concentration (mg/L)	Eff	Concentration of Removal (mg/L)	Outlet Concentration (mg/L)	Eff	Concentration of Removal (mg/L)	Standard (mg/L)
COD	16848.25	28%	4659	12189	99.7%	12150	39	-	-	400
BOD	1572	21%	333	1239	98.4%	1219	20	-	-	20
TSS	1542.5	47%	727	816	95.5%	778	37	-	-	50
NH3-N	1737.25	15%	260	1477	99.7%	1472	5	-	-	5
Colours (admi)	2794	28%	772	2022	81.2%	1642	380	73.71%	280	100

Fig. 1 - Mass Balance of the System

3.2 Drawing of Electrocoagulation Tank

The drawings of the proposed design of the electrocoagulation tank are produced using the AutoCAD software. Four views namely southeast-isometric view, top view, front view as well as side view were displayed. The dimensions are shown in the units of millimetres (mm).

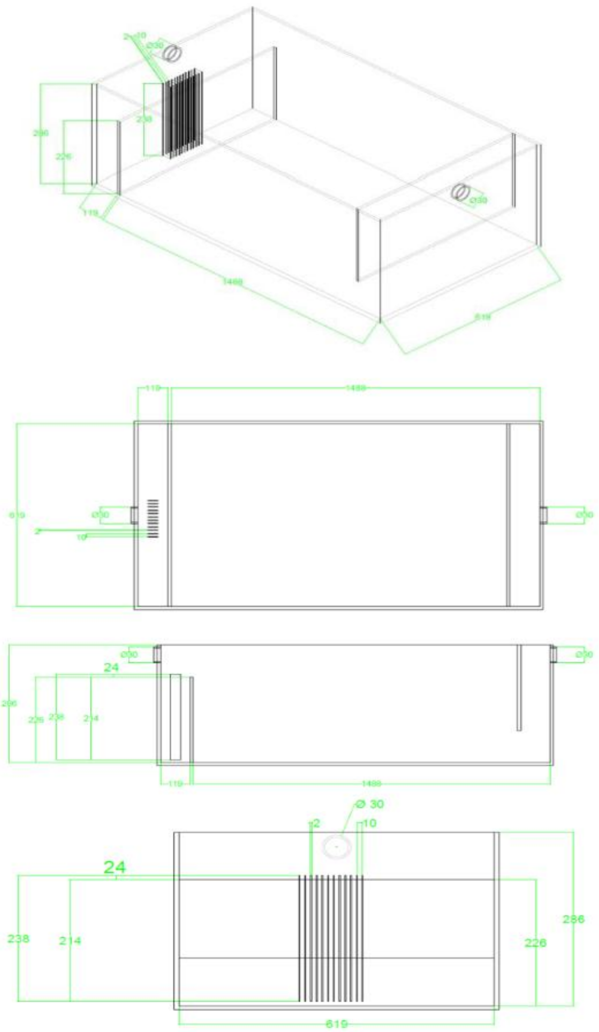

Fig. 2 - Proposed Design of Electrocoagulation Tank

3.3 Drawing of Three-zone System Tank

The drawings of the proposed design of the three-zone biological membrane system tank is produced using the AutoCAD software. Four views namely southeast-isometric view, top view, front view as well as side view were displayed. The dimensions are shown in the units of millimetres (mm).

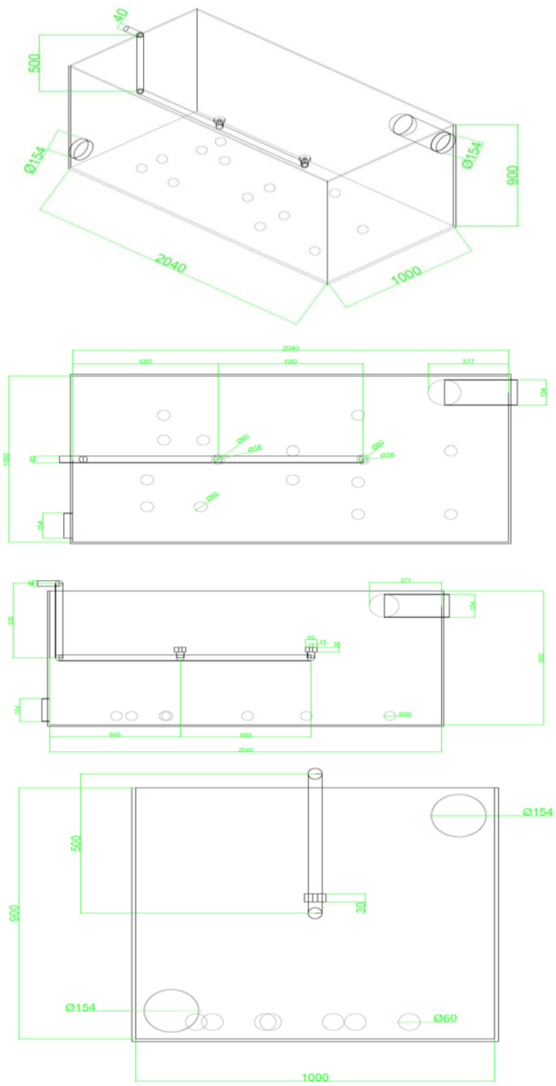

Fig. 3 - Proposed Design of Three-zone System Tank

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3.4 Overall System Drawing

Figure 4 shows the overall system drawing of the leachate treatment system prototype integrating electrocoagulation and membrane bioreactor. The leachate will first enter the electrocoagulation tank to reduce a good portion of pollutants including TSS, BOD, COD and NH_3-N as well as colour. Subsequently, the leachate will enter the three-zone biological membrane system tank in which most of the pollutants are removed. There are three zones in the tank namely anaerobic zone which is the bottommost part where biological balls are equipped for the growth of leachate treating microbes, the zone in the middle is the anoxic zone where denitrification occurs and the uppermost zone is the aerobic zone in which the nitrification as well as COD and BOD removal occur. Aeration is supplied by aerator in the anoxic zone in order to promote the movement of the carbon sources for denitrifying bacteria as well as the pollutants to be treated in respective zones. Eventually, the treated leachate will enter a bleaching tank where sodium hypochlorite is added to remove the colour of the leachate to meet the standard.

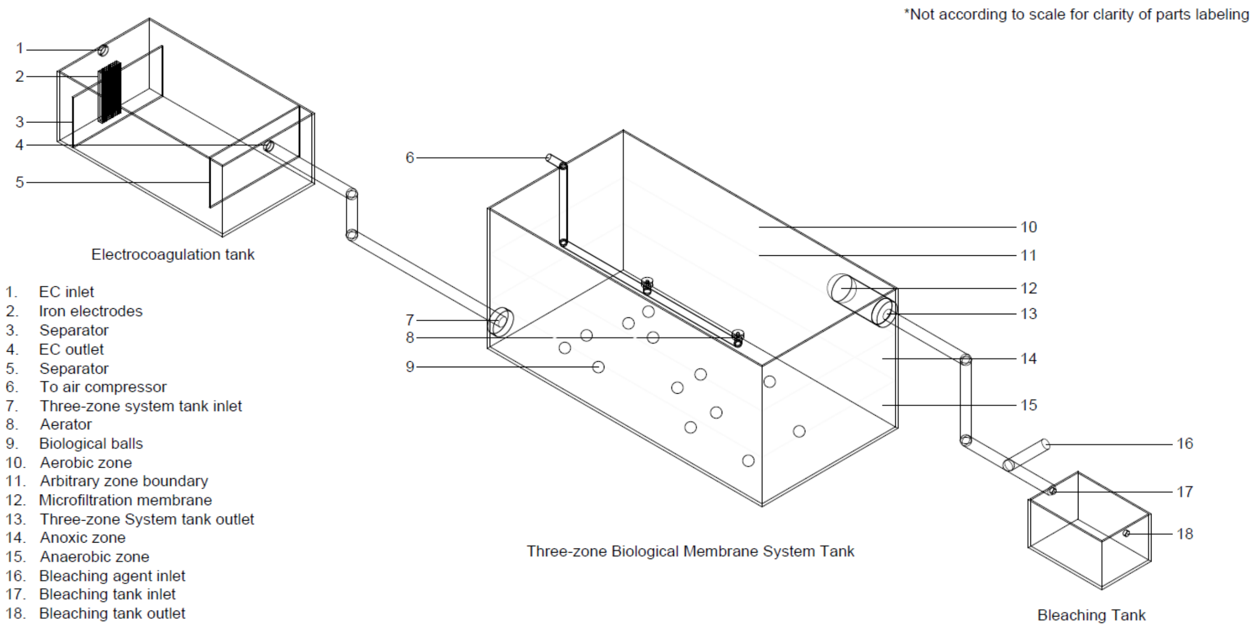

Fig. 4 - Labelled drawing of proposed prototype of leachate treatment system

4. Conclusion

In this study, the wastewater treatment system incorporates three methods of treatment unit, namely electrocoagulation (EC) and membrane bioreactor (MBR) as well as a bleaching unit. Electrocoagulation subunit is used as the pre- treatment subunit to overcome the flaw that membrane bioreactor has which is the poor removal of refractory compounds. This results in a better treatment quality of the discharge as the treatment system is combining electrochemical, biological and membrane process in a single comprehensive system. A treatment system prototype is developed by integrating EC and MBR and bleaching unit with a design that has not been patented by any research before so that the design is unique and innovative and can be patented. The optimum operating conditions from previous studies are utilized in integrating EC and MBR to obtain the design parameters. The composition of the treated leachate is set to comply with the standard set by Malaysia EQA through treatment by this prototype. The detailed drawings of this prototype are produced in a way that adheres to the standard needed to apply for a patent.

The treatment of landfill leachate using the combined system is a proper way to treat landfill leachate to produce clean discharge. This innovative treatment system is expected to reduce the water pollution caused by landfill leachate. This system is believed to bring benefits to human beings, including mitigating the problem of water pollution effectively.

Acknowledgement

This work was supported by the Universiti Teknologi Malaysia (UTM) Fundamental Research Grant (Grant No. Q.J130000.3846.22H85).

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