The Treatment of Landfill Leachate by Electrocoagulation to Reduce Heavy Metals and Ammonia-Nitrogen

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Abstract

Landfill leachate contains high concentration of contaminants in the form of nitrogen, suspended solids and heavy metals, which affects the environment adversely. Hence leachate treatment is considered vital in landfill management as the effluent needs to undergo several treatments before being discharged into natural water bodies. Without treatment, the leachate will contaminate the surface and ground water as it can penetrate through soils and subsoils. Several methods have been applied for the treatment of landfill leachate. However, these methods have several constraints due to area required and cost incurred. This paper presents the application of electrocoagulation in removing pollutants from landfill leachate: particularly ammonia-nitrogen and heavy metals. Three metals namely aluminium, iron and zinc were used as electrodes. Aluminium electrode was found to be the most effective where it was capable to extract 89% of zinc and 75% of iron in 30-minute retention time. Subsequently, 93% of zinc and 83% of iron was removed in 120 minutes. In addition, 93% of ammonia-nitrogen was also removed. These results led to a conclusion that the electrocoagulation had the capacity to remove heavy metals and ammonia-nitrogen present in landfill leachate.

Keywords: landfill leachate; ammonia-nitrogen; heavy metals; electrocoagulation

1. Introduction

Solid waste is used or unwanted substance generated by human and animal activities that cannot be reused or recycled. This type of unwanted substance is generally handled by the city municipals thus they are more known as municipal solid wastes. Municipal solid wastes are disposed by landfilling, incineration, grinding, open dumping, composting, or discharging to sewers. Landfilling operation is one of the main contributors to the environmental pollution and public health problems. In the landfill operation, solid wastes undergo physical, chemical and biological changes and they will produce various kinds of hazardous pollutants such as gas and liquid emission [1]. Liquid emission is known as leachate. It contains a large amount of organic and inorganic, highly contaminated, hazardous substances, heavy metals, pathogen and other polluted matters which harm water and soil. [2] Compositions of leachate in landfills depend on the site-specific characteristic, volume of the down-pour, stage of stabilization and high concentration of organic and inorganic matters and heavy metals contamination [3]. In the same light, leachate in landfill sites may generate serious pollution to the ecosystem and environment due to large amounts of heavy metals, ammonia-nitrogen, organic and inorganic matter in it [4]. High concentrations of heavy metals such as zinc, iron, cadmium, lead, aluminium, chromium, copper and manganese are usually found in landfill leachate [5]. Heavy metals, unlike organic matter, are not biodegradable, highly toxic and tend to accumulate in living organisms [6]. Meanwhile, wastewater rich in ammonia-nitrogen would prevent the natural nitrification, cause water hypoxia, poison fish, reduce water purification capacity and damaging the aquatic environment [7]. Treatment of landfill leachate is required to remove its contaminants as to comply with the standard of water quality before being discharged to water bodies [8]. There are several types of treatment that have been employed to treat leachate such as advanced oxidation techniques, membrane processes, biological processes and coagulation–floculation methods [9]. Another treatment is 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 [10]. Electrocoagulation too is known as a suitable technology to improve the quality of water and can be applied to a wide range of pollutants [5]. In other words, electrocoagulation is applying an electrical charge to water and change the particle of the surface charge, allowing suspended matter to form an agglomeration [11]. The performances of electrocoagulation are affected by its duration and types of electrodes used. Hence, this research aimed to evaluate the performance of electrodes in treatment of electrocoagulation in raw leachate samples. Several batch experiments at different retention time using three identified electrodes were conducted to fulfill the objective of this study.

2. Materials and Methods

In this study, raw leachate samples in the first stabilization pond of a landfill in Jeram, Selangor, were examined for the physical, chemical and heavy metals characteristics. The physical parameters tested were the pH, temperature and total suspended solid. Meanwhile, chemical test involves determination of biological oxygen demand (BOD), chemical oxygen demand (COD) and...
ammonia-nitrogen (NH$_3$-N). Amount of zinc, iron, lead, aluminium, chromium, copper and manganese were analyzed using a spectrophotometer. [12] After the initial characteristics of the raw leachate were obtained, electrocoagulation was conducted to treat the raw leachate samples in order to remove the pollutants. Figure 1 shows basic conceptual diagram of electrolysis displaying a direct current power supply (DC), a cathode and anode, and the electrolyte (a medium that provides the ion transport mechanism between the anode and the cathode necessary to sustain the electrochemical process). [13] In this research, three different electrodes, which were zinc plate, iron plate and aluminium plates, were used as the cathode and anode. The three plates were 13 cm long, 5 mm wide and 0.1 cm thick.

This experiment was run in batch modes. Each pair of the similar plates were placed parallel, 0.5 cm apart. Three batch experiments were run consecutively using the zinc, iron and aluminium plates. Electric current was run via a DC power supply to the electrodes (cathode and anode) following [14]. However, this research used small electric current by a direct power supply to the circuit (5A at 18V).

3. Results and Discussion

Table 1 shows the characteristic of raw leachate of the Jeram landfill compared to the permissible limits allowed by the Malaysian Department of Environment (DOE). The pH of this raw leachate falls within the range stipulated by the Department of Environment (DOE) while its temperature is 38˚C, lower than that of the DOE standard [8]. The turbidity, total dissolved solid (TDS) and dissolved oxygen (DO) of the leachate are 507.0 NTU, 15300.0 mg/L, and 6.5 mg/L, respectively. Table 1 also shows the concentration of the BOD at 3000 mg/L, which is very high compared to 20.0 mg/L in DOE standard [8]. The concentration of ammonia-nitrogen (NH$_3$-N) was found at 2226.0 mg/l which is way above the permissible limit at 5.0 mg/L. A high ammonia-nitrogen in the leachate would pollute the surroundings when released without treatment. The concentration of suspended solid (SS) was 600 mg/L and the concentration of organic compounds for chemical oxygen demand (COD) was 3000 mg/L. The concentrations of CaCO$_3$ (Mg) and CaCO$_3$ (Ca) were 351 mg/L and 46.0 mg/L, respectively.

The results obviously show all parameters did not comply with the DOE standard. [8] Thus the leachate effluent from the Jeram landfill needs to undergo further treatment before being released to the river. Table 2 shows the presence of heavy metals in the raw leachate samples and its comparison with the DOE standard [8]. The concentration of zinc was 362 mg/L, which was the highest in the 1L samples. The next highest was iron, which was 128.0 mg/L. This is due to the Jeram landfill being dumped with construction materials like steel, residual of electronic components, batteries, and component from automobiles. These disposals have contributed large concentrations of Zn and Fe in its leachate. Meanwhile, the concentration of plumblum (85.5 mg/L), chromium (Cr$^{6+}$) (0.6 mg/L), copper (8.0 mg/L) and manganese (1.7 mg/L) exceeded the limit permitted by the DOE. These amounts of heavy metal in raw landfill leachate are considered hazardous which requires treatment.

Table 2: Leachate Compositions after Treatment of Electrocoagulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Raw Leachate in 1L</th>
<th>DOE Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>mg/L</td>
<td>128.0</td>
<td>-</td>
</tr>
<tr>
<td>Fe</td>
<td>mg/L</td>
<td>208.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/L</td>
<td>85.5</td>
<td>0.10</td>
</tr>
<tr>
<td>Al$^{3+}$</td>
<td>mg/L</td>
<td>1.8</td>
<td>-</td>
</tr>
<tr>
<td>Cr$^{6+}$</td>
<td>mg/L</td>
<td>0.6</td>
<td>0.05</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/L</td>
<td>8.0</td>
<td>0.20</td>
</tr>
<tr>
<td>Mn</td>
<td>mg/L</td>
<td>1.7</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 3 and Table 4 show the characteristics of landfill leachate after electrocoagulation. After the procedure, data were collected to calculate the amount of the removed ammonia-nitrogen and heavy metals. Here, it can be concluded that the type of plate and duration of the electrocoagulation were the factors that contributed to the successful removal of pollutants process. [9]

Table 3: Heavy Metal Characteristics in Raw Leachate from Jeram Landfill

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Zinc</th>
<th>Iron</th>
<th>Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>24.81</td>
<td>35.61</td>
<td>70.71</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>5.47</td>
<td>5.44</td>
<td>5.51</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>626.0</td>
<td>764.0</td>
<td>858.0</td>
</tr>
<tr>
<td>Color</td>
<td>mg/L</td>
<td>208.0</td>
<td>481.0</td>
<td>671.0</td>
</tr>
</tbody>
</table>

Table 4: Plate Types in 30 minutes duration time

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Aluminium</th>
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<td>208.0</td>
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</tr>
</tbody>
</table>

Three different materials were used as electrode plates to study the performance of electrocoagulation to remove ammonia-nitrogen and heavy metals. The electrodes material consists of iron, zinc and aluminium plates. Table 3 shows the results of landfill leachate sample after the electrocoagulation by different electrodes in 30 minutes duration time. From the table, it can be seen that all three types of plates were able to reduce the amount of turbidity, COD and colour within 30 minutes. After the electrocoagulation, the leachate was filtered with Whatman Grade 1 filter paper and the zinc plate was able to reduce and shows the lowest turbidity. The COD is 626 mg/L and turbidity 24.81 NTU, respectively. However, the pH of the leachate became acidic after the treatment as the electrocoagulation had increased the pH.

This research found the high presence of heavy metals; zinc and iron in the Jeram landfill leachate (Table 2). Thus, the study was focused on the amount of zinc, iron and ammonia-nitrogen being removed. Zinc, iron and aluminium plates were used to ensure the maximum electrocoagulation in 30 minutes. The result and percentage of heavy metal and ammonia-nitrogen removal by each plate is shown in Table 4.
Table 4 shows the zinc plate removing the heavy metals and ammonia-nitrogen in the Jeram landfill leachate compared to the iron and aluminium electrodes within 30 minutes. The concentration of iron dropped from 128.0 mg/L to 20.0 mg/L and the percentage removal was 84.4%. The iron plate has caused good electrocoagulation. As this plate (zinc) underwent a redox reaction process, the iron is oxidized in the process treatment. Redox can be explained by oxidation and reduction process. This includes the removing of oxygen atoms, hydrogen atoms, or electrons involves in many oxidation and reduction process (redox). [15] Zinc is known as a good reducing agent and needs to lose an electron that requires the electron transfer. In addition, the reducing agent zinc oxidized and donated the electrons to the oxidizing agents. The reaction of zinc is shown below (1); [16]

$$Zn \rightarrow Zn^{2+} + 2e^- \quad (1)$$

Meanwhile, iron is classified as the best oxidizing agent with the gained the electron in the oxidation and reduction process (redox) and well known to be an electron receiver (2); [17]

$$Fe + e^- \rightarrow Fe^{2+} \quad (2)$$

It could be seen that, the percentage removal for all the plates in 30 minutes duration time is above 80%. Hence, zinc and aluminium plates have removed 90.3% and 91.6% of ammonia-nitrogen, respectively. Meanwhile, iron plate has removed 81% of ammonia-nitrogen from the leachate sample after electrocoagulation.

For the removal of zinc and iron in 30 minutes duration time, aluminium plate has removed 88.7% of zinc compared to zinc plate, 80.5%. However, the performance of aluminium plate has dropped to 75.4% in removing the iron compared to zinc plate (84.4%). Therefore, it can be said that the zinc plate was the best electrode to remove the iron, the heavy metal, in a short time (84.4%).

In this research, the aluminium plate was in focus to conduct the electrocoagulation due to its fast reaction compared with the zinc and iron plates. The electrocoagulation process using aluminium plate was run in 120 minutes at 30-minute interval to study the reduction of heavy metals and ammonia-nitrogen in the landfill leachate. Table 5 shows the result of heavy metals and ammonia-nitrogen after electrocoagulation process using aluminium plate in landfill leachate sample.

Hence, the existing of ammonia-nitrogen in the water would create toxic ammonia that can affect the growth rates of fishes and can harm the aquatic life. [19] In addition, zinc also can contribute to the lack of appetite and eczema in human. [20] Treatment is mandatory to reduce those pollutants (zinc, iron and ammonia-nitrogen) in this case using electrocoagulation, which will protect the water environment and ecosystem. The longer times of electrocoagulation process, the higher of removal efficiency for zinc, iron and ammonia-nitrogen. Table 5 shows that the zinc removal slightly rises from 89 % to 93 %. In addition, the iron removal is higher which is from 75% to 83%. The ammonia-nitrogen increases from 92% to 93%. The longer duration, which is 120 minutes, increases the efficiency as more bubbles are produced and the increased the time of the plate is in contact with the sample liquid. The bubbles coagulated and floated at the top of liquid (leachate) in the beaker.

From Figure 2, the result shows that the aluminium plate is the most efficient electrode in this electrocoagulation. It removed more zinc, iron and ammonia-nitrogen within 120 minutes. The longer time contributed to the higher removal of ammonia-nitrogen and heavy metals. According to [21], the surface complexation and electrostatic attraction are two vital mechanisms to remove heavy metals by electrocoagulation process.

### 4. Conclusion

In conclusion, the electrocoagulation is seen as a potential technique in the reduction of ammonia-nitrogen and heavy metals pollutants. Untreated leachate has caused serious problem to human, aquatic life and environment. The characteristics of Jeram landfill leachate have been determined to undergo treatment before being discharged to the water. In general, zinc and iron have been classified as harmful pollutants; and they are discovered to have been present in the highest concentration in the leachate of the Jeram Landfill. Given this situation and backed by the findings from this study, electrocoagulation is suggested for its treatment. Hence, the zero waste concepts for sustainable environment can be achieved by electrocoagulation as future solid waste treatment.

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References


