LANDFILL-LEACHATE TREATMENT BY PERMEABLE REACTIVE BARRIERS (PRBs) WITH WASTE MATTER AS REACTIVE MEDIA

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Abstract:

Because of possessing high potentials to contaminate surrounding ground and surface water, the landfill-leachate should undergo treatment before entering the ground and surface water. Permeable Reactive Barriers (PRBs) which are widely applied to remedy the contaminated ground water can be applied as an in-situ method for the leachate treatment. The availability and cost are important criteria in selecting reactive materials for PRBs. Therefore, this study was conducted to find out the performances of several waste matter as reactive media of PRBs. The removal efficiencies of contaminants contained in landfill-leachate were studied using laboratory-scale columns modelling PRBs. The column experimental set-up consisted of 4 columns. Each column was filled with dewatered sludge; demolition wastes; quarry dust and a mixture of organic materials such as coconut coir fiber, rice straw, saw chips, and rice husks; respectively. Each reactive material was mixed with laterite soil so that soil to reactive material ratio became 4:1 on weight. The columns were loaded with 5% leachate collected from a dumpsite. The duration of the experimental series was 46 days. Dewatered sludge showed the highest removal efficiency for COD during the initial five days and last 20 days. Its removal efficiency was more than 90% during these periods. The adsorption capacity of the dewatered sludge could be higher than the other reactive media because its removal efficiency during the initial period was nearly 100%. The BOD₅ removal efficiency of all media were satisfactory while the mixture of organic materials gave the highest removal efficiency, more than 80% throughout. Both dewatered sludge and the mixture of organic media performed equally well leading the other two media in removing nitrogenous compounds.

Keywords: Column tests, Organic materials, Nitrogenous compounds, Reactive media
1.0 Introduction

If the wastes generating from industrial operations, are not disposed of properly, they have the potential to impact adversely on the quality of the natural surface and ground water systems. Leachate leaking from unsanitary landfills contaminates the surrounding soils and groundwater because it is rich in organic matter, inorganic ions including heavy metals and micro pollutants. Therefore it is high time to investigate low-cost techniques for landfill-leachate treatment. In fact the landfills seem to remain the main solid waste disposal method in the foreseeable future of developing countries. A permeable reactive barrier (PRB) is a subsurface emplacement of reactive materials through which a dissolved contaminant plume moves as it flows, typically under natural gradient. Treated water exits from the other side of the PRB. This is an in-situ method for remediating dissolved-phase contaminants in groundwater. A PRB combines a passive chemical or biological treatment zone with subsurface fluid flow management. PRBs are considered a low cost, effective alternative for remediating contaminated sites. They are extensively used for remediating contaminated groundwater or sites.

The PRBs can be used to treat landfill leachate if the PRB wall is constructed so that it intercepts the leachate plume from a landfill. The application of PRBs as an in-situ leachate treatment method can be found across the globe. It is a good replacement for the traditional “pump-and-treat” methods which have proved unsuccessful for a number of potentially harmful chemicals, for example heavy metals leaching slowly from contaminated sources, polycyclic Aromatic Hydrocarbons (PAH) with low-bio-availability and etc.

The main engineering challenge with the PRBs is the determination of a suitable type and amount of reactive materials and proper placement techniques. The availability and the cost are also very important criteria in selecting a reactive material. PRBs can be made economical by using low-cost, locally and readily available materials as reactive media. Quarry dust, demolition waste, dewatered sludge, coconut coir fiber, saw chips, rice husks, agricultural limestone and rice straw are potential low-cost reactive materials. The application of materials such as demolition waste and dewatered sludge in PRBs would lessen the burden of their disposal. In this study a laboratory scale column experiment was conducted to study the feasibility of PRBs with low-cost, locally and readily available reactive materials to treat landfill leachate.

2.0 Methodology

2.1 Laboratory-scale filter column experiments

Figure 1 shows the column experimental set-up. It consisted of 4 columns each with 35 cm height and 8.9 cm diameter. The dimensions of columns were selected in such a way that the column length was four times greater than its diameter. This is the minimum value of length to diameter ratio suggested by Relyea et al., (1982) for this type of study. At the bottom of the column, initially existed a 7 cm thick gravel layer. In order to distribute influent and effluent evenly and prevent by-passing of water, two perforated plates were placed between the media and the gravel layer at the bottom of the column, and over the media at the top of the column. There were three holes on either side of each column as shown in figure 1, through which air from an air-compressor can be injected into the column.
The leachate from the Galle Municipal Council (GMC) dumpsite was the influent for experimental series. Initially, the leachate was collected and characterized. Table 1 shows the influent characteristics.

Each column of the filter column experimental set-up was filled with dewatered sludge, demolition waste, quarry dust and a mixture of equal amounts of rice husks, saw chips, rice straw and coconut coir fiber, respectively. At first reactive materials were prepared. Rice straw and coconut coir fiber could not be used in their original shapes. Therefore they were cut into 2cm pieces. All the organic reactive materials were washed and dried before filling in the columns. Each reactive material was mixed with laterite soil so that soil to reactive material ratio became 4:1 on weight. This ratio was selected according to a research conducted by Boum et al (2001). After filling reactive materials, the
initial compaction density was determined. Table 2 shows the characteristic of packing media in column experiment study.

After filling the columns with media, the columns were flushed out with tap water until there was negligible amount of contaminants in the effluent. The influent was stored in an overhead tank and distributed to the columns at a constant rate under the gravitational force. Influent was introduced via a shower for homogeneous distribution across the cross section of the column. The effluent was collected in an effluent tank kept below each column. Air was supplied every other day. Effluent samples were collected at different frequencies throughout the experimental series. The amount of influent added and amount of effluent discharged were recorded. Both influent and effluent samples were analysed in accordance with the Standard Methods for the Examination of Water and Wastewater (1988).

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![Table 1: Influent characteristics](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/l)</td>
<td>6427.2</td>
</tr>
<tr>
<td>BOD$_5$ (mg/l)</td>
<td>1900</td>
</tr>
<tr>
<td>NH$_3$-N (mg/l)</td>
<td>75.46</td>
</tr>
<tr>
<td>NO$_3$-N (mg/L)</td>
<td>9.58</td>
</tr>
<tr>
<td>Total-N (mg/l)</td>
<td>3200</td>
</tr>
<tr>
<td>Alkalinity (mg/l)</td>
<td>1250</td>
</tr>
<tr>
<td>pH</td>
<td>8.01</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>46</td>
</tr>
</tbody>
</table>
Table 2: Initial characteristics of packing media in column

<table>
<thead>
<tr>
<th>Column No</th>
<th>Materials</th>
<th>Weight (g)</th>
<th>Density (kg/m$^3$)</th>
<th>Initial height of the media (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dewatered Sludge+soil</td>
<td>1848.96</td>
<td>1053.036</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>Demolishionwaste+soil</td>
<td>1804.42</td>
<td>1067.7</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>Quarry dust+soil</td>
<td>2071.48</td>
<td>1177.53</td>
<td>24.5</td>
</tr>
<tr>
<td>4</td>
<td>Organic materials+soil</td>
<td>807.71</td>
<td>371.12</td>
<td>23</td>
</tr>
</tbody>
</table>

3.0 Results and discussion

3.1 Introduction

The following sub sections show the removal efficiencies of, organic materials, and nitrogenous compounds by each media during the experimental series. Since, unsaturated conditions prevailed in all four columns, the treatment mechanism was expected to be greatly similar to natural attenuation in the unsaturated zone of soil.

In the soil environment adsorption, biological uptake, ion exchange reactions, filtration, precipitation are operative. Aerobic decomposition could be dominant inside columns because the columns were aerated in addition to being opened at the top.

3.2 Removal of organic materials

The removal efficiencies of organic matter were determined in terms of BOD$_5$ and COD. In leachate BOD and COD may exist as suspended and dissolved forms. Bagghi (2004) stated that the major mechanism of COD removal is biological uptake and minor mechanism is filtration. According to Bagghi (2004), the surface of organic matter provides a place for the adsorption as well as it may be an energy source for microorganisms. Organic matter acts as a substrate for aerobic microorganisms in an aerobic environment. The reactive media provides an attached media for microorganisms. Adsorption also could be a major removing mechanism of COD. Sorption refers to the exchange of molecules and ions between the solid phase and the liquid phase. According to Zhang et al (2010) at the clayey stratum adsorption, biological uptake, cation exchange reaction, filtration, precipitation are operative. Figure 2 shows the variation of the removal efficiency of COD.

The removal efficiencies in all the columns were higher on first few days and then decreased rapidly preceding an increase again toward the end of the series. This variation gives a clue that the adsorption could be the dominant treatment mechanism during the first few days and thereafter with the decrease of vacant sites, adsorption could be dormant resulting a drop of the removal efficiency. The latter increase of the removal efficiency could be attributed to the biochemical decomposition.
which normally takes some time to execute because, it needs the synthesis of new microorganisms. The removal efficiency of COD led other media at many occasions during the experimental series. Since the removal efficiency of the dewatered sludge during the initial period was about 100 %, the dewatered sludge could possess the highest adsorption capacity for COD in landfill-leachate.

![Figure 2: Percentage removal of COD with time](image)

Figure 2: Percentage removal of COD with time
(RS/SC/CCF/RH-mixture of rice straw, saw chip, coconut core fiber, rice husk)

Figure 3 shows the variation of percentage removal of BOD5. The removal efficiencies of BOD5 by all media were more than 80 % at many occasions whereas the mixture of organic matter led other media slightly. When the removal efficiencies of COD and BOD5 were compared, the dewatered sludge had a relatively low performance in removing BOD5.

![Figure 3: Percentage removal of BOD5 with time](image)

Figure 3: Percentage removal of BOD5 with time
(RS/SC/CCF/RH-mixture of rice straw, saw chip, coconut core fiber, rice husk)

3.3 Removal of nitrogenous compounds

Nitrogen in leachate is principally in the form of ammonia or organic nitrogen, both soluble and particulate. Removal of nitrogen from leachate can be accomplished through a variety of
physicochemical and biological processes. Generally, N-removal efficiency is particularly affected by the hydraulic residence time, organic carbon availability, and establishment of anaerobic conditions (Metcalf and Eddy 2003) Figure 4 shows the percentage removal of ammonia-nitrogen by each column. During the biological treatment, most of the particulate organic nitrogen is transformed to ammonium and other inorganic forms. The highest removal rate occurred on the first three days of the experimental series. At the initial stage ammonium adsorption could happen. Adsorption is the process of collecting soluble substances that are in solution on a suitable interface. A solid-liquid interface existed in this case, in which the reactive media acted as an adsorbent. Adsorption depends on internal pore spaces within the sorption media. Adsorption rate is high when there is a large surface area. With the progression of time, the adsorbed ammonium could undergo nitrification. The execution of nitrification takes some time. Therefore the treatment mechanism of ammonium could be both adsorption and nitrification. The smaller the particles size, the more the surface area is. According to Ni-Bin Chang et al (2010) if the media provides more surface, attachments for microorganisms to form biofilms, it may allow higher nitrogen loading rates to be handled. Sorption media with a significant ion exchange capacity may provide a superior removal of ammonia nitrogen. During the initial stage, the highest ammonia removal happened in the column containing the mixture of RS/SC/CCF/RH with soil; whereas it was dewatered sludge that gave the overall higher removal efficiency after the 10th day of the experimental series. Hence organic media could be better at ammonia adsorption while the dewatered sludge could be better at supporting nitrifiers.

Kaandeepan (2012) stated that the reduction of soluble ammonia was normally enhanced by ionic attraction between ammonia ion and negative charge of clay. Therefore the all media had the capacity to undergo ammonia adsorption. The lowest removal rate occurred from 6th to 10th day. This could be due to the reduction of vacant sites. Thereafter the removal efficiency increased as a result of the execution of nitrification. Ammonium nitrogen is ultimately converted to nitrate through an autotrophic nitrification process and is also assimilated into the cells through biomass synthesis (Atlas and Bartha, 1998). Thus a significant decrease in ammonium could be caused by both its conversion and assimilation. Both dewatered sludge with soil and RS/SC/CCF/RH with soil columns presented overall greater ammonia removal.

![Figure 4: Percentage removal of Ammonia nitrogen with time](RS/SC/CCF/RH-mixture of rice straw, saw chip, coconut core fiber, rice husk)
Figure 5 shows the concentration of nitrate nitrogen with time. Initially the effluent nitrate nitrogen concentration was almost equal to that of the influent, which implies that only ammonium adsorption took place during that period. After about 10 days, the nitrate-nitrogen concentration increased in all media, which implies that nitrification executed. Nitrate nitrogen usually does not undergo adsorption owing to a high mobility. Nitrate cannot be removed by ion exchange, because soil and nitrate both are in anion form. Also anoxic environment could be developed in the reactive media.

![Figure 5: Nitrate nitrogen concentration with time](RS/SC/CCF/RH-mixture of rice straw, saw chip, coconut core fiber, rice husk)

Figure 6 shows the removal efficiency of total nitrogen with time. Total nitrogen is the sum of total kjeldahl nitrogen (organic and reduced nitrogen), ammonia, nitrate and nitrite nitrogen. According to Gebhard (1978), in the long run, denitrification and immobilization as organic nitrogen can combine with sorption and fixation to yield a net reduction of both ammonium and total nitrogen in leachate. This experimental series was conducted more than 45 days. Because of that case heterotrophic bacteria could develop. Anoxic air pockets could exist within the reactive media. Then the removal of nitrogen in the form of nitrate by conversion to nitrogen gas could be accomplished biologically. Also there is no effect in reduction of total nitrogen in terms of nitrification process. At the first stage, a higher total nitrogen removal occurred because of adsorption of ammonia. At the end it can be said that the highest efficiency happened in the columns containing dewatered sludge and organic reactive media.

4.0 Conclusion

The low-cost reactive media, dewatered sludge, demolition wastes, quarry dust and a mix of coconut core fiber/saw chips/rice husks/rice straw showed different removal efficiencies for different parameters. Overall, the dewatered sludge and the mixture of organic matter had greater removal efficiencies for all measured parameters. Biochemical decomposition and adsorption could be the major treatment mechanisms of organic materials and nitrogenous compounds in all media. However, the variation of removal efficiencies with time can be unpredictable and the media characteristic could change with time necessitating frequent reactivation of the media. Therefore, the study of the final characteristics of the reactive media is essential.
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