Performance of coir geotextiles as attached media in biofilters for nutrient removal
Gopan Mukkulath, Santosh .G.Thampi
Department of Civil Engineering, National Institute of Technology,
Calicut – 673601, Kerala, India
gopan@nitc.ac.in
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ABSTRACT
Biofilters are often used for denitrification, nitrification and carbon removal. Its main advantages are compactness and high capacity for removal of carbon, nitrogen and phosphorus. Further, they are well integrated into the environment, there is no need for secondary clarification except for certain aerobic applications, there is no need for liquid circulation for nitrogen removal, and energy consumption along with sludge production are minimum. Extensive studies have shown the utility of biofilters for efficient on-site disposal of wastewater. In this pilot plant study coir geotextile media was used as attachment media for the biofilters for low volume organic rich industrial wastewater. The geotextiles were able to decompose carbonaceous as well as nutrient compounds. In this study, the performance of biofilters employing coir geotextiles as the medium is investigated with specific reference to the removal of nutrients from wastewaters rich in organic matter. Both unwoven and woven types of coir geotextiles are used as the media. The filters were operated for six different cycles with various types of wastewaters. The results obtained show a significant nitrate removal rate and phosphate removal rate.

Keywords: Nutrient removal, Biofilters, Coir Geotextiles.

1. Introduction
A large number of biological nutrient removal process options have been developed and are used in full-scale wastewater treatment plants. Evaluation of the applicability of this wide variety of process options by potential users can be confusing, particularly for those who are not intimately familiar with the relatively minor differences, which can exist between seemingly similar process options. Differences between nutrient removal process options can sometimes result in significant differences in process performance and/or operational characteristics. In other cases, they will make little or no impact. Different process options may also simply represent different approaches to accomplish the same objectives.

1.1 Nitrogen removal
Biological nitrogen removal from industrial wastewaters is accomplished using nitrification and denitrification mechanisms (Tanaka.et.al, 1991). Nitrogen is a component of waste biomass produced as a result of biological treatment of carbonaceous organic matter. Standard procedures are available to determine the quantity of nitrogen, which will be removed by these mechanisms. Nitrogen removal will occur by this mechanism in BNR (biological nitrogen removal) systems, just as it occurs in any biological wastewater treatment system. The difference between a typical biological wastewater treatment system

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and a BNR system is that, in a BNR system, additional nitrogen removal is achieved by the combined action of the two biological reactions: (1) nitrification and (2) denitrification.

*Nitrification* is the biological conversion of ammonia-nitrogen to nitrate-nitrogen. Members of a group of bacteria called autotrophs accomplish it. Autotrophic microorganisms oxidize inorganic constituents to obtain energy for growth and maintenance, while they obtain carbon for the production of new biomass by the reduction of carbon dioxide. Notice that organic matter is not required for the growth of autotrophic bacteria. Nitrification is actually a two-step reaction. The first step is oxidation of ammonia-nitrogen to nitrite-nitrogen by bacteria of the genus Nitrosomonas. The equation for this reaction, presented in simplified format, is as follows:

\[
\text{NH}_4^+ + 1.5 \text{O}_2 \rightarrow \text{NO}_2^- + 2\text{H}^+ + \text{H}_2\text{O} \quad (1)
\]

The second step is the oxidation of nitrite-nitrogen to nitrate-nitrogen by bacteria of the genus Nitrobacter. The simplified equation for this reaction is as follows:

\[
\text{NO}_2^- + 0.5 \text{O}_2 \rightarrow \text{NO}_3^- \quad (2)
\]

Under steady-state conditions these two reactions will be in balance and the overall reaction will go essentially to completion. Including the synthesis of new biomass (expressed as the typical composition of biomass), the overall reaction is:

\[
\text{NH}_4^+ + 1.83 \text{O}_2 \rightarrow 1.98 \text{HCO}_3^- - 0.98 \text{NO}_3^- + 0.021 \text{C}_3\text{H}_7\text{NO}_2 + 1.88 \text{H}_2\text{CO}_3 + 1.04 \text{H}_2\text{O} \quad (3)
\]

Denitrification is the utilization of carbonaceous organic matter by heterotrophic bacteria using nitrate-nitrogen as the terminal electron acceptor (i.e. the "oxygen source"). Many of the heterotrophic bacteria in biological wastewater treatment systems are capable of using either dissolved oxygen or nitrate-nitrogen as a terminal electron acceptor. Dissolved oxygen is used preferentially when both terminal electron acceptors are present. This occurs since slightly more energy can be obtained by the oxidation of carbonaceous organic matter using oxygen as the terminal electron acceptor than when nitrate-nitrogen serves as the terminal electron acceptor. However, dissolved oxygen and nitrate-nitrogen provide essentially the same biochemical function. When nitrate-nitrogen serves as the terminal electron acceptor (i.e. denitrification occurs), the nitrate-nitrogen is converted to nitrogen gas, which can then be liberated into the atmosphere. This reaction is the removal of nitrogen from the wastewater stream.

**1.2 Biological phosphorus removal process**

The biological phosphorus-removing microorganisms contain high concentrations of polyphosphate, a phosphate polymer in which individual phosphate molecules are linked by high-energy bonds. The phosphate, which is generated as a result of the cleavage of the high-energy phosphate-to-phosphate bonds, diffuses out of the cell, resulting in an increase in soluble phosphate concentration. The release of phosphate and concurrent uptake of organic material takes place. However, when the phosphorus accumulating microorganisms subsequently pass into the aerobic zone where oxygen is provided to allow aerobic metabolism, they oxidize the stored organic matter and generate energy which is used to take up phosphate from solution and store is as polyphosphate.
Polyphosphate is the biological phosphorus-removing microorganisms have been characterized as a "battery" which stores chemical energy for use as needed. The "battery" is discharged in the anaerobic zone to provide the energy necessary to transport and store soluble organic matter. It is then "recharged" in the aerobic zone as the stored organic matter is oxidized to generate the necessary energy. This characterization, although simplified, is accurate. Note also that the stored polyphosphate is responsible for the high phosphorus content of the phosphorus-removing microorganisms. Consequently, any factor, which encourages the metabolic pattern described above, also improves the phosphorus removal capability of the process.

In summary, the mechanism responsible for the selection of the high phosphorus content microorganisms in a biological phosphorus removal process is cycling of the microorganisms between anaerobic and aerobic environments. The process influent wastewater is added to the anaerobic zone. Since the phosphorus removing microorganisms are able to take up and store the soluble organic matter contained in the influent wastewater while other heterotrophic microorganisms are not, the phosphorus removing microorganisms are placed at a competitive advantage and the population is enriched in these microorganisms. Because of the high phosphorus content of these microorganisms, the phosphorus content of the mixed liquor is increased. As a consequence, the mass of phosphorus contained in the WAS removed from the process is increased, resulting in a reduced mass of phosphorus in the process effluent.

The basic configuration of a biological phosphorus removal system consists of an initial anaerobic zone, which receives return activated sludge (RAS) from the clarifier and the process influent wastewater. The uptake of soluble organic matter occurs in this zone, along with the corresponding release of phosphate. The mixed liquor then flows out of the anaerobic zone and into the aerobic zone where organic matter is oxidized and phosphate uptake occurs. The phosphorus-removing microorganisms grow relatively slowly (but generally faster than the nitrifying bacteria). Both laboratory and full-scale experience indicate that a process MCRT on the order of 3 days must be maintained to avoid washout of the phosphorus-removing bacteria. Typically the hydraulic residence time in the anaerobic zone is 0.75 to 1.0 hour based on the process influent flow rate. Factors, which affect the size of the anaerobic zone, are discussed below.

However, in such a configuration biological phosphorus removal is adversely affected if the aerobic zone is large enough to allow nitrifying bacteria to grow. This adverse impact occurs because nitrification in the aerobic zone results in the production of nitrate-nitrogen, which is recycled to the anaerobic zone in the RAS flow stream. Thus recycle of nitrate-nitrogen provides a terminal electron acceptor in the initial mixed zone that allows heterotrophic denitrifying bacteria to compete with the phosphorus removing bacteria for organic matter contained in the influent wastewater. Under these circumstances, a reduced competitive advantage is provided for the phosphorus-removing bacteria, resulting in reduced enrichment of the population with high phosphorus content microorganisms and reduced biological phosphorus removal capability. As a consequence, a variety of process configurations have been developed which restrict the recycle of nitrate-nitrogen to the anaerobic zone in nitrifying biological phosphorus removal systems.

2. Materials and method

2.1 Materials properties
Coir is a hard and tough organic fibre extracted from the husk of coconut. It is rich in cellulose and lignin, besides having high specific area and wetting ability factors which are essential for bacterial adhesion in fixed film processes (Praveen, 2008). Geotextiles are planar sheets which may be woven, non-woven or knitted which are relatively thick. They are capable of transmitting fluids across or in-plane or both but can retain suspended particles. Woven geotextiles are manufactured by interlacing fibres usually at right angles. While the non-woven type by mechanical, heat or chemical bonding of directional or randomly oriented fibres (Ramanatha Ayyar, 2002). The different types of coir geotextiles and their physical properties are given in the table.

Table 1: Properties of Coir geotextiles

<table>
<thead>
<tr>
<th>Designation</th>
<th>Mass/unit area(g/m²)</th>
<th>Thickness(mm)</th>
<th>Aperture size(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2M1</td>
<td>758.18</td>
<td>6.42</td>
<td>9x12</td>
</tr>
<tr>
<td>H2M2</td>
<td>864.8</td>
<td>6.79</td>
<td>8x17</td>
</tr>
<tr>
<td>H2M4</td>
<td>1286.56</td>
<td>8.39</td>
<td>10x2</td>
</tr>
<tr>
<td>H2M5</td>
<td>727.14</td>
<td>7.03</td>
<td>8x10</td>
</tr>
<tr>
<td>H2M6</td>
<td>401.44</td>
<td>6.46</td>
<td>25x25</td>
</tr>
</tbody>
</table>

*(Rao, and Balan, 2000)*

Based on the properties listed in the Table 1. H2M2 designated coir geotextile is used in the experimental setup. Standard sand which conforms to IS 650:1982 which (100 percent) pass through 2mm IS sieve and shall be (100 percent) retained on 90-micron IS sieve with the following particle size distribution having uniformity coefficient of one is used for media in sand filter. It is thoroughly washed with deionized water to remove the dust, clay and attached organic impurities. Synthetic wastewater was prepared for the desired parameters.

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smaller than 2mm and greater than 1mm</td>
<td>33.33</td>
</tr>
<tr>
<td>Smaller than 1mm and greater than 500µ</td>
<td>33.33</td>
</tr>
<tr>
<td>Smaller than 500µ and greater than 90 µ</td>
<td>33.33</td>
</tr>
</tbody>
</table>

Table 2: Packing density and porosity of the attached media

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sand</th>
<th>Woven</th>
<th>Non Woven</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packing Density (kg/m³)</td>
<td>1163.64</td>
<td>71.13</td>
<td>57.85</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>39.8</td>
<td>84.4</td>
<td>78.55</td>
</tr>
</tbody>
</table>

Loading rate constitute an important role in the organics removal of biofilters. Based on the studies conducted by (Korkut, 2003) adopting the loading rate on geotextiles biofilters above 365 l/m².day will drastically lower the organics removal rate and will increase rate of incremental decreases in permeability, \( \Delta K \)loss. Considering these factors a loading rate of 200L/m².day was adopted for the biofilters operation.

2.2 Sample preparation

Synthetic wastewater was prepared in the laboratory so the influent parameters remain constant throughout the filter operation. Considering the characteristics of various low
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volume organic rich industrial effluents (Nemerow, 1978), (Bhatia, 2002), (Wang, 2006). The parameters were fixed according to the type of wastewater selected. The influent characteristics are given in table below. The constituent’s of the synthetic wastewater includes the starch powder, di-potassium hydrogen phosphate (K₂HPO₄), potassium nitrate (KNO₃), in proportion to obtain the required parameters.

Table 3: Influent characteristics

<table>
<thead>
<tr>
<th>Type of Wastewater</th>
<th>BOD (mg/l)</th>
<th>COD (mg/l)</th>
<th>pH</th>
<th>TDS (mg/l)</th>
<th>Nitrates (mg/l)</th>
<th>Phosphates (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canteen</td>
<td>228</td>
<td>340</td>
<td>5.9</td>
<td>820</td>
<td>116</td>
<td>120</td>
</tr>
<tr>
<td>Laundry</td>
<td>720</td>
<td>880</td>
<td>8.1</td>
<td>2028</td>
<td>254</td>
<td>224</td>
</tr>
<tr>
<td>Food – Processing</td>
<td>7680</td>
<td>9600</td>
<td>6.7</td>
<td>582</td>
<td>183</td>
<td>112</td>
</tr>
</tbody>
</table>

Experimental setup consists of a PVC pipe of 20cm diameter and 90cm in depth with attached media packed inside as per the packing density given in Table 2. The schematic diagram of the experimental setup is given below.

Figure 1: Experimental setup

Experimental procedure consists of the following operations
a) Preparation of synthetic wastewater.
b) Synthetic wastewater is fed into the overhead tank.
c) Synthetic wastewater from the overhead tank flows to the filters through inlet pipes
d) The flow rate is adjusted using the peristaltic pump in the inlet pipe.
e) The effluent is collected and tested for different parameters.
The parameters were analyzed using methods prescribed in Standard Methods for the Examination of Water and Wastewater: published by American Public Health Association (Rice 2005).

3. Results and discussion

Coefficient of co-relation = ±0.9797

**Figure 2:** Nitrate concentration in the effluent

Coefficient of co-relation = ±0.9585

**Figure 3:** Nitrate concentration in the effluent
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Figure 4: Nitrate concentration in the effluent

Canteen Wastewater

Figure 5: Phosphate concentration in the effluent

Coefficient of co-relation = ±0.9585

Coefficient of co-relation = ±0.9928
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**Figure 6:** Phosphate concentration in the effluent

**Figure 7:** Phosphate concentration in the effluent
4. Conclusion / Suggestions/ Findings

4.1 Nitrate Removal

The filter operations were conducted for three operational cycles with three different types of waste water. The percentage nitrate removal rates obtained for canteen wastewater are 83.53, 86.1 and 81, that for laundry wastewater are 87.4, 89.3 and 82.7 and that for food processing wastewater are 77.7, 82 and 73.37 for woven coir geotextiles ,unwoven coir geotextiles and plastic media respectively. Considering the overall performance the un-woven coir geotextile media filter was found to be most efficient as far as Nitrate removal. This can be attributed to low packing density and better conditions (anoxic) for nitrification and denitrification in unwoven coir geotextiles.

4.2 Phosphate removal

The percentage nitrate removal rates obtained for canteen wastewater are 93.3, 95 and 85, that for laundry wastewater are 89.3, 92 and 79.2 and that for food processing wastewater are 85.5, 85.8 and 78.6 for woven coir geotextiles ,unwoven coir geotextiles and plastic media respectively. This results shows that un woven coir geotextiles have a better phosphate removal rate. Coir geotextile provides a better attachment media than sand for the growth of microorganisms. It was also observed that the filter clogging was minimum in coir geotextile filters.

5. References


22. Porter, K.E., (1979), Plastic media biological filters, Water pollution control, pp 371-379,


