Removal performance and mechanism of TP in constructed rapid infiltration system

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Abstract

The constructed rapid infiltration system (CRIS) is a new wastewater treatment technique. At present, the research on pollutants degradation performance and mechanism is relatively scarce and the removal rate of TP is very low. With this in mind, a simulation CRIS column was applied to treat domestic wastewater and the degradation performance and mechanism of TP were studied. The results show that in the CRIS, the phosphorus removal efficiency is low, and the removal rate is only 44.58%. And here are the reasons: First, CRIS adopts river sand with little amount of ferrous, aluminum, calcium and other active materials as the main filling material of the CRIS, therefore, the removal rate of TP by absorption and precipitation is low. Next, the CRIS filling material is high in permeability, the period of pollutants contacting with filling material is short, and that leads to the phosphorus and the positive electrical ions in the filling material cannot adequately react and precipitate. Therefore, to increase the removal rate of TP in CRIS, it is necessary to begin from developing novel filter material.

Keywords: TP; Removal performance and mechanism; Constructed Rapid Infiltration system

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1. Introduction

Traditional sewage land treating systems suffer from several ubiquitous shortcomings and disadvantages, such as lower hydraulic load rates, lower wastewater treating capabilities per unit area, being easy to plug and so on [1-4]. To overcome the hurdles mentioned above, Mr. Zhong Zuosheng and some other researchers in China University of Geosciences invented
CRIS based on the traditional rapid infiltration and the constructed wetland systems. Here is its working principle: the mixtures of 90% natural sands, 5% marble sands and 5% zeolite sands are filled in the rapid infiltration pond as the artificial filter material, then the rapid infiltration pond is fed wastewater once every six hours and the water flowing direction within it is vertical down; when wastewater goes through the filter layer, the biofilm will grow on the surface of the filter materials; then the biofilm and the filter medium will retain and adsorb those dissolved substances and suspended materials present in wastewater; meanwhile, the highly concentrated biofilm, attached to the high specific surface area of the filter material, rapidly depurates the pollutants in wastewater [5-7]. Due to the simple operation, low engineering investment, small amount of operation cost and other advantages of CRIS, it is of important application value to the wastewater disposal of China’s small and medium towns. Currently, CRIS has been widely applied in projects. As practice proves, CRIS is stable in operation, and most of the water indicators are up to standard, and the removal rates of CRIS to COD, BOD, SS and ammonia nitrogen are all above 85%, but the removal rate of CRIS to TP is as low as 40% which cannot meet the A-level of primary standard in Municipal wastewater treatment plant emission standards (GB 18918-2002) [8]. The phosphorus in wastewater land treatment system is mainly removed by filling material absorption, chemical precipitation, bacterial activity, plant uptake and other ways, wherein the filling material plays an important role, and it has always been publically regarded as the ultimate destination of phosphorus in the land treatment system. Now, many scholars have paid attention to the selection of filtrating material, the operation mode, the contamination removal efficiency, etc [9-11]. However, systematic knowledge about the pollutant degradation characteristics in CRIS is still very superficial. With this in mind, our study focused on applying the simulation soil column of CRIS in treating domestic wastewater and investigating the TP degradation dynamics characteristics, which could optimize the CRIS treatment process and provide valuable references for factual design and operation in engineering.

2. Experimental material and method

Experimental installation: A CRIS simulation column was constructed in lab. The main body of the reactor was composed of a hard PVC pipe with 200 cm in height and a internal diameter of 21 cm; the filter material consisted of 90% natural sand, 5% marble sand and 5% zeolite sand (The particle sizes and the relative contents of filler materials were shown in Table 1; the filter porosity is shown in Table 2), and the height of filter layer was 150 cm. A sample port was placed at every 25 cm from the upper layer to the bottom. A glass tube float flowmeter was applied to adjust the hydraulic load. The influent was continuous and the fluid flow direction was vertical down from the top to the bottom of the filter layer (Fig.1) [5].

Experimental methods: In order to be more close to the fact, the domestic wastewater was adopted as the experimental water sample. CRIS started up with raw wastewater. The hydraulic load is an important design and operational parameter in CRIS. When the CRIS analog column is mature, it went on operating under the hydraulic load of 1.00 m/d to study the TP degradation laws. The test ran from August 2 2011 until August 11 2011. Test methods were shown in Table 3.
Table 1. The particle sizes and the relative contents of filler materials

<table>
<thead>
<tr>
<th>Particle size range (mm)</th>
<th>Natural sand</th>
<th>Marble sand</th>
<th>Zeolite sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2.0</td>
<td>11</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>1.0-2.0</td>
<td>28</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>0.56-1.0</td>
<td>35</td>
<td>24</td>
<td>19</td>
</tr>
<tr>
<td>0.25-0.56</td>
<td>14</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>&lt;0.25</td>
<td>12</td>
<td>20</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 2. Filter porosity

<table>
<thead>
<tr>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural sand</td>
</tr>
<tr>
<td>42%</td>
</tr>
</tbody>
</table>

Table 3. Test methods of pollutant indexes

<table>
<thead>
<tr>
<th>Index</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Glass-electrodes method</td>
</tr>
<tr>
<td>COD</td>
<td>Potassium dichromate method</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>Nessler's reagent colorimetry</td>
</tr>
<tr>
<td>TN</td>
<td>Alkaline potassium per sulfate digestion-uv spectrophotometric method</td>
</tr>
<tr>
<td>TP</td>
<td>Ammonium molybdate spectrophotometric method</td>
</tr>
</tbody>
</table>

3. Result and analysis

Table 4 indicates the TP removal property of CRIS in the condition of 1m/d of hydraulic load and 6h of hydraulic load period. In the CRIS, the average water inflow concentration is 4.47mg/L, and the average water outflow concentration is 2.45mg/L. The TP removal rate of CRIS is weak, with an average removal rate of 44.58% and the TP water outflow
concentration being not up to the A-level of primary standard in Municipal wastewater treatment plant emission standards (GB 18918-2002).

**Table 4. Removal capacity of TP in CRIS**

<table>
<thead>
<tr>
<th>Sampling number</th>
<th>Inflow Concentration (mg/L)</th>
<th>Outflow Concentration (mg/L)</th>
<th>Removal rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.52</td>
<td>2.36</td>
<td>47.78</td>
</tr>
<tr>
<td>2</td>
<td>4.55</td>
<td>2.51</td>
<td>44.83</td>
</tr>
<tr>
<td>3</td>
<td>4.23</td>
<td>2.36</td>
<td>44.20</td>
</tr>
<tr>
<td>4</td>
<td>4.58</td>
<td>2.44</td>
<td>46.72</td>
</tr>
<tr>
<td>5</td>
<td>3.69</td>
<td>2.62</td>
<td>28.99</td>
</tr>
<tr>
<td>6</td>
<td>5.12</td>
<td>2.52</td>
<td>50.78</td>
</tr>
<tr>
<td>7</td>
<td>5.33</td>
<td>2.41</td>
<td>54.78</td>
</tr>
<tr>
<td>8</td>
<td>4.25</td>
<td>2.39</td>
<td>43.76</td>
</tr>
<tr>
<td>9</td>
<td>4.12</td>
<td>2.22</td>
<td>46.11</td>
</tr>
<tr>
<td>10</td>
<td>4.36</td>
<td>2.71</td>
<td>37.84</td>
</tr>
<tr>
<td>average</td>
<td>4.47</td>
<td>2.45</td>
<td>44.58</td>
</tr>
</tbody>
</table>

Combining the migration and transformation mechanism of phosphorus in traditional wastewater land treatment system, this research analyzes the removal mechanism of phosphorus in CRIS and the reason why the phosphorus removal rate of CRIS is weak. In traditional land wastewater treatment system, the removal of phosphorus is mainly by means of plant uptake, percolation absorption, chemical precipitation, microbial accumulation, etc. As there are no plants in the CRIS, CRIS removes phosphorus mainly by filter material absorption, chemical precipitation and microbial accumulation. The filter material has certain absorption role for the polluted materials. When wastewater flows through the CRIS filter material, the phosphorus in the wastewater is absorbed by the filter material through the role of diffusion, but this process is reversible. Because the phosphorus concentration in the wastewater is low, the phosphorus absorbed on the filter material would return to the wastewater solution. The filter material plays the role of buffering agent in this process. In the land wastewater process system, the filter material always has a certain amount of ferrous, aluminium, calcium and other active substances. These active substances easily experience hydroxyl proton and thus take positive electrical charges, generating Fe$^{3+}$, Al$^3$ and Ca$^{2+}$. Those ions taking positive electrical charge are easily and mutually attracted with the phosphate anions taking negative electrical charges, and then generate phosphate which is difficult to be soluble in water. The equations for these reactions are as following:

\[
\text{Ca}^{2+} + \text{OH}^- + \text{HPO}_4^{2-} = \text{Ca}_5(\text{PO}_4)_2 \downarrow + \text{H}_2\text{O} \tag{1}
\]

\[
5\text{Ca}^{2+} + 4\text{OH}^- + 3\text{HPO}_4^{2-} = \text{Ca}_5(\text{OH}_2\text{PO}_4)_3 \downarrow + 3\text{H}_2\text{O} \tag{2}
\]

\[
\text{Fe}^{3+} + \text{H}_n\text{PO}_4^{3+n} \rightarrow \text{FePO}_4 \downarrow + n\text{H}^+ \tag{3}
\]

\[
\text{Al}^{3+} + \text{H}_n\text{Al}_5^{3+} \rightarrow \text{AlPO}_4 \downarrow + n\text{H}^+ \tag{4}
\]
While, to have higher hydraulic load in the CRIS, this research adopts river sand which is of high permeability as the main filling material of the system. As the river sand has very little ferrous, aluminium, magnesium, calcium and other active materials, the removal rate to phosphorus by absorption and precipitation role is low. Still, as the CRIS filling material is high in permeability, the hydraulic load is high, therefore the contact period of pollutants and filter materials is short, which leads to the positive ions in the phosphorus and the filter material not to better react and precipitate. In the wastewater land process system, the microorganism around the filter material has accumulation role for the phosphorus in the wastewater, but the phosphorus absorbed by the microorganism would once return to the water body as the death of microorganisms, and this is only a process of dynamic absorption and release and cannot radically eliminate the phosphorus in the system. Therefore, the assimilation of the microorganism in the system to phosphorus and the excessive phosphorus accumulation of polyphosphate accumulation bacteria are weak to remove phosphorus. However, the microorganism has very important role in phosphorus removal, therefore the microorganism can transform the organic phosphor into inorganic phosphorus which can be absorbed by plants, be absorbed and precipitated by the positive electrical ions in the filter material. From the phosphorus removal mechanism, it is obvious that traditional CRIS has very low efficiency of removing phosphorus.

4. Conclusion

In CRIS, the filling material plays a very important role in phosphorus removal and is the ultimate destination of phosphorus. The removal rate of phosphorus is closely related to the physical and chemical properties of substrate. The TP removal efficiency of the CRIS is low, and the removal rate is only 44.58%. Two reasons are: First, CRIS adopts river sand with little amount of ferrous, aluminum, magnesium, calcium and other active materials as the main filling material of the system. Therefore, the removal rate of CRIS to phosphorus by absorption and precipitation is low. Next, the CRIS filling material is high in permeability, the period of pollutants contacting with filling material is short, and that leads to the phosphorus and the positive electrical ions in the filling material cannot adequately react and precipitate. The co-precipitation of phosphorus and positive ion are the decisive factors to remove phosphorus in the wastewater. The type and the content of positive ions in the CRIS filling material determine the phosphorus removal capability of CRIS. Therefore, to increase the removal rate of CRIS to phosphorus in the wastewater, it is necessary to begin from developing novel filter material.

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