STUDY ON CAPACITY OF A TRICKLING FILTER USING BIOCHAR MEDIUM FOR TREATING WASTEWATER FROM AN CUU MARKET IN HUE CITY, VIETNAM

Nguyen Thi Cam Yen*
Institute of Resources and Environment – Hue University, 7 Ha Noi St., Hue, Vietnam

Abstract. Pollution caused by market wastewater has occurred for many years in Vietnam. In particular, untreated wastewater from a riverside market is often directly discharged into a river, increasing loads of pollutants for the river. Every day, An Cuu market wastewater is averagely discharged about 19 cubic metres into An Cuu river. However, a wastewater treatment system has not been yet built at the market due to many reasons including the lack of investment capital. A Trickling filter (TF) consisting of a fix bed of biochar is a cost acceptable technology, effectively treating parameters like organic pollutants, nutrients and suspended solids. In this study, a model of TF using biochar medium for An Cuu market wastewater treatment were effectively operated with the organic loading rate (OLR) varying from 188 to 550 gBOD5.m-3.day-1 and the hydraulic loading rate (HLR) from 532 to 1899 L.m-2.day-1. The biochar trickling filter showed high removal efficiencies: 97% BOD5, 92% COD, 97% TSS, 66% Ptot and 62% Ntot.

Key words: An Cuu market, wastewater treatment, biochar trickling filter, Vietnam

1 Introduction

An Cuu market is a famous market locating next to An Cuu river in Hue city, Vietnam. In recent years, An Cuu river has been polluted. One of waste sources affecting An Cuu river water quality is wastewater from An Cuu market. Every day, wastewater from this market is averagely discharged about 19 cubic metres into the river. In 2015, An Cuu market wastewater was discharged with a flow of 8 m3.day-1 carrying nutrient loads of 438 g.day-1 and 302 g.day-1 in nitrogen and phosphorus, respectively into the river [12]. However, until now, the management board of An Cuu market has not been able to build a wastewater treatment system due to difficulties in capital source and land area. Therefore, finding a suitable technology solution for treating An Cuu market wastewater is truly necessary and useful.

TF also called biological TF is a traditional wastewater treatment technology normally consisting of a fix bed of rocks, sand, gravel or ceramic over which wastewater flows downward and causes a layer of microbial slime (biofilm) to grow and cover the bed of filter material [16]. However, using these traditional filter materials often leads to some restrictions on performance of treatment such as clogging after a short time of application, high bulk density, low porosity.

*Corresponding: ntcyen@hueuni.edu.vn
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and low specific surface area. To increase the surface area of sand material in a filter, it needs decreasing sizes of sand particles. However, this leads to a sooner clogging phenomenon in the filter. Meanwhile, biochar has recently attracted much attention in wastewater field thanks to its superior properties. “Biochar is a carbon-rich solid product formed by pyrolysis of bio-organic materials at middle to low temperature (< 700 °C) under anoxic conditions” [4]. There are plenty of studies about application of biochar to adsorb pollutants in wastewater, because of its low-cost preparation, high surface area, large pore volume, plentiful functional groups, and environmental stability [4]. Many research results have shown a high capacity of biochar filter for wastewater treatment. For example, in study of Korbinian Kaetzl and colleagues (2018), an anaerobic biochar filter was used for municipal wastewater treatment. The research results showed that COD (up to 90%), TOC (up to 80%) and turbidity could be significantly reduced [7]. M.M. Manyuchi and colleagues (2018) studied to use biochar biofilter to treat municipal wastewater. As a result, COD, TSS, TKN and P$_{\text{Tot}}$ showed a 90%, 89%, 64% and 78% reduction respectively after being passed through the biochar biofilter [8]. Study of Sahar S. Dalahmeh (2016) showed that performance of biochar filter for domestic wastewater treatment was better than sand filter. In addition, capacity of biochar filter against fluctuation of OLR and HLR was also better than sand filter. Biochar can be used for adsorption of heavy metals, organic substances, including high molecular compounds used in agriculture, medicine and manufacturing industries. Studies using biochar for removing heavy metals from wastewater accounted for 46% while studies on removing organic by biochar accounted for 39% [17].

Although biochar is a kind of material with a lot of strong properties for wastewater treatment application, it has not been much studied for this field in Vietnam. Meanwhile, biomass sources of Vietnam for producing biochar are plentiful. If calculating biomass from agriculture and timber, Vietnam ranks only the 3rd in Southeast Asia, after Indonesia and Thailand [10]. Simultaneously, the sources of biomass in Vietnam are diverse, estimated at over 100 million tons per year and potential biomass types are husks, leaves, bagasse and natural forest trees [13]. Therefore, this study was carried out to test An Cuu market wastewater treatment capacity of a TF using commercial biochar made from sawdust as the filter material.

2 Materials and Methods

2.1 Sampling and sample analysis

An Cuu Market wastewater were taken and moved to lab of Institute of Resources and Environment – Hue University (IREN) to preserve and analyze basic parameters, including: Dissolved oxygen (DO), pH, Chemical oxygen demand (COD), Biochemical oxygen demand after five days (BOD$_5$), total suspended solids (TSS), total nitrogen (N$_{\text{Tot}}$) and total phosphorous (P$_{\text{Tot}}$). Single wastewater samples were taken according to guiding of the international standard ISO
5667 -10:1992 and sample preservation was based on the international standard ISO 5667-3:2003. Wastewater sampling was carried 1- 2 times per month in 5 months including March, May, July, September and December 2018 and one time per month in February and May, 2019. Sample analysis was conducted according to guiding of national and international standards [1]. Triplicate analysis was conducted for each wastewater sample with parameters including pH, DO, TSS, BOD₅, COD, N_Tot and P_Tot to control the test quality through repeatability [2].

2.2 Filter Design and Experimental Setup

The experimental setup consisted of:

1. A reservoir containing raw wastewater with a capacity of 20 litres, placed at the height of 1.8 metres above the ground so that wastewater moved by gravity to a filter column at a lower altitude. At the bottom of the reservoir, there was a drain valve connected to a 8-mm diameter pipe for moving wastewater into the filter column. The end of the inlet pipe was connected with a water split pipe to distribute the wastewater to the surface of the filter material.

2. The filter column was designed with a cylindrical structure, made of PVC with an inner diameter of 100 mm and a height of 1 m. Inside the column, biochar filter material was stuffed with a height of 0.6 m and below it, locating a 20-cm layer of gravel with a grain size of 10 – 25 mm for the role of a drainage layer. At the elevation 10 cm from the bottom of the column, arrange a valve to drain treated effluent.

3. The filter column was supplied by an oxygen blower operating continuously with an aeration speed of 2.5 litres per minute and the max aeration depth of 0.5 m from the middle of the column to the top. This created an aerobic condition at the top half part of the filter column and an anoxic condition at the bottom.
2.3 Material filter

Filter material used in this experiment was commercial biochar made from sawdust. The sawdust biochar is one of commercial product of Viet Renewable Energy Technology Joint Stock Company with the characteristics is described as follows:

![Figure 1. Schematic diagram of experimental setup for testing wastewater treatment effects by biochar filter material](image-url)
Table 1. Characteristics of commercial sawdust biochar

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total energy value</td>
<td>kcal/kg</td>
<td>&gt; 7000</td>
</tr>
<tr>
<td>2</td>
<td>Fixed-carbon content</td>
<td>%</td>
<td>80 - 95</td>
</tr>
<tr>
<td>3</td>
<td>Sulphur content</td>
<td>%</td>
<td>0 – 0.01</td>
</tr>
<tr>
<td>4</td>
<td>Humidity</td>
<td>%</td>
<td>&lt; 4</td>
</tr>
<tr>
<td>5</td>
<td>Carbonization temperature</td>
<td>°C</td>
<td>&lt; 1000</td>
</tr>
</tbody>
</table>

Production process of the commercial biochar

Sawdust was pressed and formed into each hexagonal cylinder block and processed through a continuous pyrolysis kiln at a temperature of approximately 1000 °C.

Biochar filter material preparation

The commercial biochar made from sawdust was crushed and screened through sieves with different sizes to achieve different granular composition in mass. The uniformity coefficient is a numeric estimate of how the filter material is graded. In this study, it was calculated by dividing the d60 value (the size of screen opening where 60% of a sample passes through and 40% is retained) by d10 value (the size of screen opening where 10% of a sample passes through and 90% is retained) [11]. In this study, uniformity coefficient = 2.5.

Biochar material disposition inside the filter column

The biochar filter material with the height of 0.6 m was put into a 1 mm mesh bag and stuffed along the height of the filter column. It comprised three layers with different particle sizes. The material layer at the bottom consisted of particles with sizes of 10 - 15 mm, accounting for 39.9 % in mass. The middle layer consisted of particles with sizes of 4 - 10 mm, accounting for 49.7 % in mass. The top layer was the bed of particles with sizes of 1 - 4 mm, accounting for 10.4% in mass. The drainage material layer located at the bottom of the column was 0.2 m high, made of crushed stones with sizes of 10 – 25 mm washed with tap water to remove stone dust.

2.4 Wastewater and Biological Sludge

The influent used for the experiment was wastewater taken from An Cuu market, Hue city, Vietnam. The wastewater was diluted with tap water to change concentrations of pollutants for testing performance of the biochar filter in wastewater treatment. However, before the tap water was used, it had been removed chlorine gas through natural evaporation for 24 hours.

Biological sludge used for the experiment was activated sludge taken from an aeration tank in Phu Bai industrial zone wastewater treatment plant, Thua Thien Hue province, Vietnam. The
biological sludge was fed with An Cuu market wastewater at organic loading rate of 0.2 – 0.3 \( \text{mgBOD}_5 \text{.mgVSS}^{-1} \text{.d}^{-1} \) (VSS - Volatile Suspended Solid).

2.5 Preparation for experiment

The biochar filter column was operated with tap water in three days to make air inside the column escape out and to monitor and control operation parameters including flow, HLR and hydraulic retention time. Subsequently, biofilm was developed inside the filter column by mixing a quantity of activated sludge into diluted wastewater to gain concentrations of the forming solution 144 mg.L\(^{-1}\) and 190 mg.L\(^{-1}\) in TSS and BOD\(_5\), respectively; then pouring the solution into the filter column and aerating continuously. In the following days, the filter column was operated with diluted wastewater gaining BOD\(_5\) concentration of 200 mg.L\(^{-1}\) and surface loading rate of 506 L.m\(^{-1}\).day\(^{-1}\). The microbiological culture period lasted 12 days (when the output COD concentration was stable).

2.6 Operating parameters

The biochar filter column was fed with wastewater with the HLR in the range of 532 – 1899 L.m\(^{-2}\).day\(^{-1}\). Through diluting wastewater to change concentrations of pollutants and controlling the opening of the drain valve of the storage reservoir to change the OLR and HLR. The experiment was conducted with the OLR in the range of 188 – 550 g.BOD\(_5\).m\(^{-3}\).day\(^{-1}\).

Parameters pH, TSS, BOD\(_5\), COD, N\(_{\text{Tot}}\), P\(_{\text{Tot}}\) in wastewater before and after treatment were analyzed to evaluate the treatment effectiveness of the biochar filter. In addition, the operating parameters include OLR and HLR calculated by following formulas.

\[
\text{OLR} = \frac{Q \times Lo}{1000V_{vl}}
\]

\[
\text{HLR} = \frac{Q}{S}
\]

\(Q\): L.day\(^{-1}\), wastewater flow; \(Lo\): mg.L\(^{-1}\), influent concentration of organic matters; \(V_{vl}\): m\(^3\), volume of biochar filter material; OLR: g.m\(^{-3}\).day\(^{-1}\), organic loading rate; S: m\(^2\), cross-sectional area of the filter column; HLR: L.m\(^{-2}\).day\(^{-1}\), hydraulic loading rate (surface loading rate)

3 Results and Discussion

3.1 Characteristics of An Cuu market wastewater

Characteristics of An Cuu market wastewater did not meet the National Technical Regulation on Domestic Wastewater QCVN 14:2008/BTNMT for parameters including organic
pollutants and suspended solids. Values of these parameters exceeded many times the limit of the regulation. In detail, characteristics of the wastewater were shown in the following table

3.2 Removal of pollutants by the biochar TF

Concentrations of pollutants in wastewater before and after treatment by the biochar filter column were shown in the following table.

The above table showed that concentrations of pollutants in wastewater after treatment by biochar filter met limits of the National Technical Regulation on Domestic Wastewater QCVN 14:2008/BTNMT.

Table 1. Concentrations of pollutants in An Cuu market wastewater during the survey period from March 2018 to May 2019. The average value shown are mean ± standard deviation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>2018 Min - max</th>
<th>Average</th>
<th>2019 Min - max</th>
<th>Average</th>
<th>QCVN 14:2008/BTNMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>6.2 – 7.3</td>
<td>6.7 ± 0.4</td>
<td>6.5 – 7.1</td>
<td>6.8 ± 0.4</td>
<td>5-9</td>
</tr>
<tr>
<td>DO</td>
<td>mg.L(^{-1})</td>
<td>2.8 - 3.9</td>
<td>3.5 ± 0.4</td>
<td>2.8 – 3.3</td>
<td>3.1 ± 0.4</td>
<td>-</td>
</tr>
<tr>
<td>TSS</td>
<td>mg.L(^{-1})</td>
<td>57 - 190</td>
<td>124 ± 45</td>
<td>133 - 220</td>
<td>177 ± 62</td>
<td>50</td>
</tr>
<tr>
<td>BOD(_5)</td>
<td>mg.L(^{-1})</td>
<td>180 - 360</td>
<td>249 ± 67</td>
<td>128 - 220</td>
<td>174 ± 65</td>
<td>30</td>
</tr>
<tr>
<td>COD</td>
<td>mg.L(^{-1})</td>
<td>338 - 747</td>
<td>499 ± 174</td>
<td>272 - 540</td>
<td>406 ± 190</td>
<td>-</td>
</tr>
<tr>
<td>N(_{Tot})</td>
<td>mg.L(^{-1})</td>
<td>3.1 – 67.2</td>
<td>22.1 ± 21.8</td>
<td>44.5 - 108.4</td>
<td>76.5 ± 45.2</td>
<td>-</td>
</tr>
<tr>
<td>P(_{Tot})</td>
<td>mg.L(^{-1})</td>
<td>1.74 – 11.8</td>
<td>5.96 ± 3.8</td>
<td>16.1 – 19.1</td>
<td>17.6 ± 2.12</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2. Wastewater treatment effectiveness of biochar trickling filter (the values shown are mean ± standard deviation, n = 20. Triplicate analysis was conducted for each test)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Inflow (mg.L(^{-1}))</th>
<th>Effluent (mg.L(^{-1}))</th>
<th>Removal (%)</th>
<th>QCVN 14:2008/BTNMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD(_5)</td>
<td>221 ± 79</td>
<td>20 ± 10</td>
<td>90 ± 6</td>
<td>30 50</td>
</tr>
<tr>
<td>COD</td>
<td>457 ± 162</td>
<td>92 ± 39</td>
<td>79 ± 8.9</td>
<td>-</td>
</tr>
<tr>
<td>TSS</td>
<td>168 ± 60</td>
<td>24 ± 20</td>
<td>87 ± 8.1</td>
<td>50 100</td>
</tr>
<tr>
<td>N(_{Tot})</td>
<td>43.5 ± 28.2</td>
<td>21 ± 16.8</td>
<td>55 ± 8.4</td>
<td>-</td>
</tr>
<tr>
<td>P(_{Tot})</td>
<td>7.53 ± 5.2</td>
<td>4.38 ± 3.2</td>
<td>41 ± 11.9</td>
<td>-</td>
</tr>
</tbody>
</table>
Effect of the biochar filter on removal of organic matter

**BOD$_5$ removal**

The experiment was carried out with HLR ranging from 532 L.m$^{-2}$.day$^{-1}$ to 1899 L.m$^{-2}$.day$^{-1}$. At each HLR, the biochar filter was operated with a gradual increase in substrate concentration until wastewater treatment performance decreased. Accordingly, the OLR ranged from 144 to 550 g BOD$_5$.m$^{-3}$.day$^{-1}$. The concentration of BOD$_5$ in inflow was from 46 to 370 mg.L$^{-1}$. The concentration of BOD$_5$ in effluent was from 3.6 to 38 mg.L$^{-1}$. BOD$_5$ removal performance increased and reached the max value of 97% at the OLR of 362 g BOD$_5$.m$^{-3}$.day$^{-1}$. When the OLR increased to 445 - 550 g BOD$_5$.m$^{-3}$.day$^{-1}$, BOD$_5$ removal performance decreased to 78 - 80%. The correlation between BOD$_5$ removal efficiency and OLR occurred in the inverse direction, with the correlation coefficient reaching the average value $R = -0.567$. The performance of biochar filter in removal of BOD$_5$ varying according to the different OLRs is shown in Figure 2.

![Figure 2](image-url)

**Figure 2.** BOD$_5$ removal performance of biochar filter varying according to the different OLRs
On the other hand, BOD5 removal performance of the biochar filter also depended on HLR (Figure 3). With the HLR ranging from 532 to 1458 L.m-2.day-1 (equivalent to flow velocities of 0.038 – 0.103 m.h-1 inside the column), the BOD5 removal performance remained at high values in the range of 89 – 97%. However, when the HLR was increased to 1772 – 1899 L.m-2.day-1, BOD5 removal performance decreased clearly to lower than 80%.

It means that performance of the biochar filter in BOD₅ removal depends both on OLR and HLR.

In addition, comparing with similar researches, this study found quite good results. For example, Nguyen Vo Chau Ngan and partners studied to treat fish processing wastewater by a TF with filter materials made from sawdust and cocopeat. Their TF was operated with HLR ranging from 393 to 450 L.m⁻².day⁻¹ and gained BOD₅ removal of 89 – 93% [9]. Meanwhile, the biochar TF in this study was operated with an average HLR of 994 L.m⁻².day⁻¹, 2.36 times higher than Chau Ngan’s study but its BOD₅ removal performance reached up to 97%. Another example that is a research of Doan Van Dong on treating Muong La district hospital wastewater in Son La province by TF. It was conducted at a lower OLR but BOD₅ removal efficiency was lower than this study’s result. Doan Van Dong’s TF applied synthetic plastic material as filter medium with a porosity of 90%, the specific surface area of 200 – 250 m².m⁻³ and was operated with an OLR of 200 g BOD₅.m⁻³.day⁻¹. However, it just gained a BOD₅ removal performance of 88.8% [5].

![Figure 3](image.png)

**Figure 3.** Performance of biochar filter in removal of BOD₅ by HLR
In research of Sahar S. Dalahmeh (2016), domestic wastewater was treated by a biochar filter with a low HLR varying from 32 to 128 L.m\(^{-2}\).day\(^{-1}\) and a low OLR in the range of 38.8 to 197 g\(\text{BOD}_5\).m\(^{-3}\).day\(^{-1}\). That biochar filter gained an average \(\text{BOD}_5\) removal of 93% [11]. Meanwhile, the biochar TF in this study was operated with higher values of OLR and HLR than Sahar S. Dalahmeh’s biochar filter but still gained an average \(\text{BOD}_5\) removal of 90%.

From a number of comparisons of this study’s results with other studies’ results as above, it can be found that the performance of the biochar TF in this study was quite good when it was operated with higher values of OLR and HLR. This achievement is thanks to the strengths of commercial biochar filter material. It has a structure with the high fixed - carbon content and the high porosity which leads to the higher surface specific area. Therefore, its structure facilitates the better settling and adsorption compared with other traditional filter materials such as sand or gravel, etc. This result also shows that efficiency of TF with biochar material in removal of organic matters is better than traditional TF in the comparative aspects as follows:

Thus, the biochar filter preliminary shows a capacity of operating with the OLR of 1.8 times higher than traditional trickling filters (using filter materials such as macadam, pebble, gravel, slag) to gain \(\text{BOD}_5\) removal performance above 90%. At the same time, the biochar filter can receive inflow with \(\text{BOD}_5\) concentration of 1.85 times higher than the \(\text{BOD}_5\) concentration limit of traditional trickling filter without causing an overload phenomenon and is also able to adapt to the shock of OLR from low to high and vice versa.

COD removal

Performance of the biochar filter in COD removal varied from 59 to 92% with the mean value of 80%. The correlation coefficient between \(\text{BOD}_5\) removal efficiency and COD removal is strong with value \(R = 0.683\). The chart of COD removal efficiency is shown in Figure 4. Compared with another similar research, COD treatment efficiency of this study gains similar and somewhat better results. For example, in a research of Bui Thi Vu and colleagues, an anaerobic filter with coal slag material was used to treat noodle production wastewater but only gained the highest COD removal efficiency of 74% [15].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Traditional TF</th>
<th>Biochar TF</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{BOD}_5) concentration in inflow ( mg.L(^{-1}))</td>
<td>(\leq 200)</td>
<td>Up to 370</td>
</tr>
<tr>
<td>HLR (m(^3).m(^{-3}).day(^{-1}))</td>
<td>1 ÷ 3</td>
<td>0.87 ÷ 3,12</td>
</tr>
<tr>
<td>OLR (g(\text{BOD}_5).m(^{-3}).day(^{-1}))</td>
<td>100 ÷ 200</td>
<td>144 ÷ 550</td>
</tr>
<tr>
<td>Performance (%)</td>
<td>Completely removal (&gt; 90%)</td>
<td>Up to 97%</td>
</tr>
</tbody>
</table>
Effect of the biochar filter on removal of TSS

Performance of the biochar filter in TSS removal varied from 76 to 97% (Figure 5). Initially, TSS removal efficiency varied in proportion to TSS concentration in inflow but after that it was an inverse relationship. In the period from the 3rd day to the 8th day of the experiment, when input TSS concentration increased, TSS removal efficiency also increased. Conversely, from the 9th day onwards there was an inverse relationship. When the input TSS concentration increased, the TSS removal efficiency decreased and a decrease of the input TSS concentration led to an increase of TSS removal. It was because on the 9th day, the input TSS concentration gained the max value of 260 mg.L⁻¹. As known, TSS concentration of an inflow for a traditional TF is normally limited lower than 150 mg.L⁻¹ to prevent the TF from the clogging [3]. However, in this study, the input TSS concentration varied from 57 to 260 mg.L⁻¹ in which 70% of TSS values was higher than 150 mg.L⁻¹ but TSS removal performance still gained high value. This was because the porosity of the filter column was quite high with the value 59%. In detail, with the input TSS concentration in the range of 156- 260 mg.L⁻¹, TSS removal performance was averagely 85.4% and output TSS concentration gained averagely 30.7 mg.L⁻¹, meeting the A level of national technical regulation on domestic wastewater quality QCVN 14:2008/BTNMT. Besides, the correlation between TSS removal efficiency and flow velocity inside the biochar filter column was median inverse with R = -0.58. It means that TSS removal performance tends to decrease when the flow velocity increases.
Effect of the biochar filter on removal of nutrients

Total nitrogen removal

The biochar filter eliminated 36 - 62% of $N_{Tot}$ in the wastewater with an average performance of 55%. $N_{Tot}$ removal performance was relatively stable during the experimental period from the 2nd day to the 8th day, fluctuating slightly in the range of 60 - 62%, corresponding to the OLR of 188 – 228 g_BOD5.m⁻³.day⁻¹. For the experimental series from the 9th day to the 15th day, $N_{Tot}$ removal performance decreased slightly and fluctuated around 57 - 62%, corresponding to the OLR of 272 - 367 g_BOD5.m⁻³.day⁻¹. However, in the experimental series from the 16th day to the 19th day, the performance dropped sharply to only 36 - 43%. This can be explained by the increase in OLR 1.2 - 2.93 times higher than previous experiments. In contrast, on the 20th day, when the OLR decreased to 144 g_BOD5.m⁻³.day⁻¹, $N_{Tot}$ removal performance increased again to approximately 60%. Performance of the biochar filter in $N_{Tot}$ removal is shown in Figure 6.

This result initially compared with the research result of Sahar S. Dalahmeh (2016) was somewhat better. Biochar filter of Sahar S. Dalahmeh gained a stable $N_{Tot}$ removal efficiency around 50% but with an OLR much lower than OLR of the biochar filter in this study (as presented above). Also according to Sahar S. Dalahmeh (2016), sand filter often only removes lower than 5% of $N_{Tot}$. Thus, this shows that $N_{Tot}$ removal efficiency of the biochar filter can be up to 12 times higher than sand filter. This is obviously an outstanding advantage of a biochar TF compared with a TF using traditional filter materials. The reason for high performance of $N_{Tot}$ removal is because biochar material has a much larger surface area and porosity than sand; thus it facilitates the formation of higher microbial film density and longer contact time between wastewater and microorganisms. Therefore, the processes such as nitrogen assimilation in biofilm and denitrification takes place more inside a biochar biofilter than inside a sand biofilter. This leads to the higher $N_{Tot}$ removal efficiency of the biochar biofilter than sand biofilter’s performance. In addition, the adsorption of ammonium from wastewater by biochar also contributes to the increase of $N_{Tot}$ removal efficiency.

Total Phosphorus removal

In this study, $P_{Tot}$ concentration in the influent wastewater ranged from 1.05 to 16.1 mg.L⁻¹. $P_{Tot}$ concentration in the wastewater after treatment by biochar filter column was in the range of 0.55 - 10.3 mg.L⁻¹. $P_{Tot}$ removal efficiency of the biochar filter column ranged from 22 to 66% with the average value of 41% and did not tend to fluctuate clearly. However, the pH in the effluent fluctuated in the range of 7.65 - 8.74 and showed a moderate correlation with $P_{Tot}$ removal efficiency, with the correlation coefficient $R = 0.554$. The reason for this is explained as follows: Phosphorus can be normally removed from wastewater through two mechanisms including biological process and physicochemical process. To remove phosphorus by biological method, it needs to direct flow of wastewater from anaerobic zones to aerobic zones. However, in this study,
wastewater flowed in the opposite direction that was from the aerobic zone to the anaerobic zone; therefore it removed phosphorus insignificantly. Meanwhile, phosphorus can be adsorbed by some metals being present on the biochar surface such as aluminium (Al), iron (Fe) and canxiium (Ca). This adsorption process depends partly on pH. This study found that the relationship between pH and P$_{Tot}$ removal efficiency was a moderate proportional relationship. This is possible due to the presence of Al, Ca and Fe on the biochar surface.

The performance of P$_{Tot}$ removal is presented in the Figure 6.

3.3 Estimated cost of the biochar TF for An Cuu market wastewater treatment

The cost of the biochar TF for An Cuu market wastewater treatment is calculated as follow:

Cost of the TF construction

This cost is calculated based on the tank’s volume (V). The volume is calculated from the formula:

$$V = \frac{Q \times L}{OLR}$$

V: m$^3$, the tank’s volume; Q: m$^3$.day$^{-1}$, An Cuu market wastewater flow, Q = 19 m$^3$.day$^{-1}$; L: g.m$^{-3}$, the influent BOD$_5$ concentration, L = 360 g.m$^{-3}$; OLR: g.m$^{-3}$.day$^{-1}$, organic loading rate, OLR = 360 g.m$^{-3}$.day$^{-1}$

Thus, the biochar TF’s volume is 19 m$^3$ corresponding to the construction cost around 57 million VND with the unit price of 3 million VND per cubic metre.
Cost of biochar material

The commercial biochar made from sawdust is popularly sold with the price from 12000 to 20000 dong per kilo. The necessary volume of biochar material is 19 m$^3$ (about 9.5 tons) with the corresponding price ranging from 114 to 190 million VND.

4 Conclusions

This study found that capacity of biochar TF for the market wastewater treatment was quite good. The biochar TF can remove up to 97% of BOD$_5$, 97% of TSS, 62% of N$_{Tot}$ and 66% of P$_{Tot}$. Meanwhile, the commercial biochar made from sawdust is popularly sold with the price from 12000 to 20000 dong per kilo. To treat An Cuu market wastewater with the max BOD$_5$ concentration of 360 mg.L$^{-1}$ and the flow 19 m$^3$.day$^{-1}$, the investment cost only ranges from 114 to 190 million VND and the min area of the biochar filter surface is 13 m$^2$ corresponding to the HLR of 1460 Lm$^{-2}$.day$^{-1}$. This is an acceptable cost for market wastewater treatment at present. On the other hand, biochar filter materials can be reused as fertilizers or fuels. Therefore, this is a proper technical solution for the decision maker to choose for An Cuu market wastewater treatment.

References

5. Doan Van Dong, Vietnam Institute for Building Science and Technology (2009), Study on proposal of wastewater treatment system for Muong La district hospital, Son La province, Vietnam.


12. Truong Quy Tung (2015), Analysing of nitrogen and phosphorus flows from domestic waste in Hue city and recommendation of solutions for management, *Final report of scientific research project at Hue University level*.


