Performance of a Modified Trickling Filter Packed with Different Substrates in Polishing Aquaculture Wastewater

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Abstract: Sustainable use of natural resources is one of the most critical aspects in today’s world, water monument being one of them. There is a high demand for water in domestic, agricultural and industrial sector. As a result of these there is an increased rate of wastewater generation. To ensure sustainable use of the resource, there is need for wastewater management that will ensure reuse and reduce pollution to the water resource. The aim of the study was to evaluate the performance of different locally available substrate materials in polishing aquaculture wastewater before it is discharged to the receiving bodies and to determine the substrates’ optimal treatment conditions in a modified trickling filter system. The wastewater was characterized with high levels of nitrates, nitrites and phosphates which are nutrients responsible for the degradation of water resources through eutrophication. A modified trickling filter system was fabricated and woodchips, maize cobs and sugarcane bagasse were each packed in three different reactor tanks. These substrates were subjected to similar operating conditions of substrate column heights of 14 cm, 18 cm and 22 cm, varied HRT (Hydraulic Retention Time) at 12 h, 24 h, 48 h and 60 h respectively. Wastewater was collected from a fish pond and passed through the modified trickling filter system for a specified period of time. Samples of the effluent were collected and tested for nitrates, nitrites and phosphates using a UV VIS (Ultraviolet-visible) spectrometer. The results obtained showed that the contaminant with the highest concentration was nitrates. Nitrites was converted into nitrates during the treatment process hence it was not a suitable parameter to be used to make conclusions. Phosphate was present in lower concentrations compared to nitrates hence the desired level was achieved. The most suitable substrate in the removal of all the contaminants was the woodchips with an efficiency of 94% at an operating condition of 18 cm and 22 cm substrate column height for the small and large woodchip particles at 48 and 60 h HRT respectively. Maize cobs and sugarcane bagasse both yielded an efficiency of 92% at 22 cm substrate column height and 60 h HRT.

Key words: Aquaculture, wastewater, HRT.

1. Introduction

Globally, environmental sustainability is the most critical aspect of humanity. In order to maintain a sustainable environment, technologies of wastewater management need to improve over the years. Water is a basic necessity for all living organisms. It makes up about 80% of living organisms. The demand for fresh water supply is high leading to stiff competition for its use in the different sectors mainly the domestic, industrial and agricultural sectors [1]. Therefore, there is an urgent need for the treatment, recycle and reuse of wastewater to compliment the available water sources. Wastewater is referred to water that has undergone a certain process. The composition of the water depends on the process the water has gone through. Therefore, the treatment process depends on the contaminants present in the water. The largest volume of wastewater production is from domestic and industrial processes. Domestic wastewater is characterized by high levels of BOD (Biochemical
Oxygen Demand) and COD (Chemical Oxygen Demand), high levels of nitrogen due to yellow water from the toilets, and other contaminants found in soaps and detergents.

In domestic wastewater, nitrogen exists in the form of organic and inorganic nitrogen. Phosphorus in wastewater is in the form of ortho-phosphate and organically bound phosphate, which is the limiting factor in fresh water and controls the efficiency of wastewater treatment system [2].

The nature of rampant economic activities such as fish farming and crop production along the banks of water resources leads to pollution caused by wastewater containing high levels of organic load, nitrogen pollutants and other ions. These contaminants find their way into the water bodies as a result, they lead to degradation of the receiving water bodies. In some fresh water bodies for instance Lake Victoria, this has led to the invasion of water hyacinth, eutrophication and decrease in the population of fish [3]. As a result, the water body loses its fundamental utility values and aesthetics. Leaching of ions into the ground water also leads to contamination of the ground water sources. Aquaculture sector has been growing and is currently producing more than 40% of the global fish production [4]. With the increase in fish production there is an increase in wastewater generation characterized with high levels of organic load and nitrogen-based contaminants, which leads to destruction of water sources. Nitrogen-based contaminants are responsible for the eutrophication in water bodies which cause oxygen depletion leading to loss of biodiversity in the aquatic ecosystem. Aquatic species are also affected by contaminated environment leading to decrease in their population [5].

1.1 Trickling Filters

Trickling filters are wastewater treatment systems designed with a reactor tank packed with inert material where a film of aerobic and anaerobic microorganisms grows. The wastewater flows from the top of the reactor tanks to the bottom and it gets in contact with the microorganism. The bacteria break down the organic content in the wastewater as it flows down to the outlet [6, 7]. The wastewater is applied at the top through a rotary arm. As the wastewater trickles downwards, it makes the biofilm wet, and it is then exposed to the air voids present in the media, the oxygen from the air is made available to aerobic bacteria grown in the biofilm by diffusion of oxygen through the biofilm. Organic matter from the wastewater is adsorbed on the biofilm layer and it is degraded by the aerobic bacteria present in the biofilm. As the thickness of the film layer increases the condition near the surface of the media becomes anaerobic because of limited oxygen supply. The microbes will then lose their ability to cling to the surface of the inert material and the layer sloughs off and is washed out along with flowing liquid. The design of a trickling filter depends on the design of the hydraulic system and the distribution system. The diameter of a mechanical trickling filter relies on the type of equipment used for spraying water. The use of trickling filters relies mostly on pretreated water for this reason there is need for continuous monitoring and repair to avoid clogging and accumulation of excess biomass in the system. In addition to the use of trickling filters a design that will ensure minimal cost of operation is important to consider for the installation of water treatment systems for a local farmer. This includes using gravity instead of electric pumps in the flow of water and use of locally available material as filter substrate materials.

The efficiency of a trickling filter depends on the design parameters. There are different types of bioreactor systems with different concepts of design. A trickling filter design is based on the relationship of the degree of wastewater to be treated and the required filter volume. The research considered a modified form of the film bioreactors also known as solid state bioreactors. This is where the microorganisms are allowed to grow on a solid surface which also acts as a
substrate. The efficiency of the system relies on the functionalities of the microorganism, organic loading rate, hydraulic loading rate and ambient conditions [8]. Therefore, the design parameters of a system must consider the limiting factors of microbial functions i.e. pH, temperature, organic loading, hydraulic loading and availability of oxygen. There are different theories of design of a trickling filter depending on whether it is low rate loading or high rate loading trickling filter. High rate trickling filters have a hydraulic loading rate of 10 to 40 m³/m² and an organic loading rate of 0.3 to 1 kg BOD/m². On the other hand, a low rate filter has a hydraulic loading rate of 1 to 4 m³/m² and an organic loading rate of 0.08 to 0.32 kg BOD/m² [6, 8].

1.2 Substrate Material

A bioreactor is defined as a system where the process of conversion of complex compounds takes place due to the action of micro-organisms. Substrate plays an important role in microbial culture development. Non-organic materials such as rocks, synthetic and plastics have been used as bioreactors media. However, to increase its efficiency a carbon-based media is used in the bioreactors as a substrate material. This is because carbon-based media provides the energy requirements for the bacterial growth which is important for the action of nitrifying and denitrifying microorganisms. In low oxygen concentration, the microorganisms use the nitrate to metabolize the carbon in the process converting it to atmospheric nitrogen. Several carbon-based materials have been used in previous experiments with activated carbon being the most popular. This is because of its filtration and adsorptive properties [9]. Activated carbon is generated from lignite coal. The cost of manufacture of activated carbon is high since it includes a number of processes. Various carbon-based materials are refined and processed to generate activated carbon. Activated carbon has high efficiency of adsorption of complexes and ions [10]. However, due to the long-term unsustainability of coal resources, environmental concern and potentially increasing costs of production, the proposed substrate materials for this study were wood chips, sugar cane bagasse and maize cobs. These were used in a modified trickling filter as substrates in polishing aquaculture wastewater by removing nitrates, nitrites and phosphates.

2. Material and Methods

The study design for this research was experimental design since it required laboratory analysis. Qualitative and quantitative analysis was carried with a view of determining the effect of different substrate on the treatment efficiency of modified trickling filters in the removal of nitrates, nitrites and phosphates in aquaculture wastewater. Experimental research design provided the techniques for quantitative data collections and analysis.

2.1 Substrate Materials

Three substrates were used in the study: woodchips, maize cobs and sugarcane bagasse. The substrates were used in their dried form. According to Lepine, et al. [11] the HRT (Hydraulic Retention Time) has an impact on the performance, therefore, a comparison between the efficiency of the substrate at different HRT was done. The substrates particle size was manipulated at two levels with the large particle having its longest dimension between three and seven inches long and the fine/small particle with its longest dimension less than one inch.

2.2 Sampling

Samples from each reactor were collected separately in labeled glass sampling bottles after every operating condition of water treatment. The collected samples were transported to the laboratory within the hour of collection and refrigerated. The samples were tested within 6 h of collection to protect the integrity of the results. Three samples of the raw water were collected and tested before treatment so as to compare the
performance of each bioreactor in order to determine the most efficient substrate and treatment condition.

2.3 Effluent Analysis

The samples were collected and analysed at each operating condition. The operating conditions varied with reference to the following: varied particle sizes and substrate column height at 14 cm, 18 cm and 22 cm, and different HRT at an interval of 12 h, 24 h, 48 h and 60 h respectively. The samples collected were tested for the following parameters: nitrates, nitrites, phosphates.

The analysis of parameters was done using the procedure in the *Standard Methods for the Examination of Water and Wastewater* [12] to test the concentration of nutrients of interest namely nitrates, nitrites and phosphates from the effluent. The ultra violet and visible light spectrometer UV VIS (model 1800 Simdzu) from Sino-Africa-Joint-Research Center (SAJOREC) laboratories at JKUAT were used.

2.4 HRT

The system was subjected to different retention time of 12, 24, 48 and 60 h at each substrate column height of 14, 18 and 24 cm and different substrate particle size so as to determine the most suitable retention time. To achieve this, the loading flow rate and volume were varied, such that to increase the retention time small volumes were loaded at a low flow rate and to reduce the retention time large volumes of waste water were loaded at a high flow rate, this was adopted from the research by Mburu, et al. [8]. For each bioreactor concentration of the contaminants at different retention times was recorded. The optimal HRT was then determined using a model linear equation. The efficiency of the trickling filters was calculated using Eq. (1).

\[
%E = \frac{X_n - x}{x} \times 100
\]

Where:
\( %E \) = percentage efficiency;
\( X_n \) = least value of contaminant detected (mg/L);
\( x \) = value of contaminant in raw water (mg/L).

3. Results and Discussion

Characteristics of Wastewater

The wastewater was collected in sample bottles and tested in a set of three replications, the mean value ± standard deviation was compared to set standards as presented in Table 1.

From Table 1, it can be seen that for all parameters under consideration, nitrates, nitrites, phosphates, BOD and COD test results from sampled raw aquaculture wastewater were above set standards listed in EMCA 1999 under the water quality regulation of 2006. These results show that there was need for the wastewater to be polished before disposal. Many authors have reported similar findings: according to Mburu, et al. [8] the aquatic wastewater from ponds in the Lake Victoria is high in nutrients responsible for eutrophication and overgrowth of water hyacinth. In all the studies by the different authors [3, 8, 10] the recommendations were that the wastewater needs to undergo treatment before reuse or disposal. In this study, a similar recommendation was adopted in order to polish the wastewater by reducing the concentration of nutrients of interest to levels that meet the legislative recommended values for disposal.

3.1.1 Nitrates

The graphs in Figs. 1-3 present the performance of the different bioreactors in the removal of nitrates at different operating conditions. The values on the graph are the mean experimental value obtained from three replications.

| Table 1 | Raw water contaminant levels. |
|---------|-------------------------------|
| Parameters | Mean ± SD | Standards from EMCA |
| Nitrates  | 208 ± 1.24 mg/L | 100 mg/L |
| Nitrites  | 24.5 ± 0.4 mg/L | 100 mg/L |
| Phosphates | 20.66 ± 0.3 mg/L | 5 mg/L |
| BOD      | 152.6 ± 2.4 mg/L | 30 mg/L |
| COD      | 126 ± 2.1 mg/L | 30 mg/L |
| Temperature | 22 ± 0.4 °C | 22 °C |
| pH       | 6.33 ± 0.16 | 5-8 |

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(a) Nitrate Removal by Woodchips

Fig. 1 shows the plotted results of nitrate removal by woodchips.

From Fig. 1, 22 cm height of substrate for both large and small particle size and 18 cm height of substrate of small particles yield the best results in the removal of nitrates from the wastewater. The woodchip bioreactor is optimal at the operating conditions of: 22 cm substrate column height, small substrate particles and an HRT of 48 h at this point only 15 ± 0.5 mg/L of nitrate is present in the effluent. A substrate column height of 22 cm for large particles and 18 cm for small particles at an HRT of 60 h yield 18 ± 0.6 mg/L and 31 ± 0.5 mg/L respectively. The performance of the small woodchip particles was better than that of the large woodchip particle when they are subjected to constant time and substrate column height.

(b) Nitrate Removal by Maize Cobs

The results of nitrate removal by maize cobs were plotted into a graph labeled Fig. 2.

Fig. 2 shows the optimal operating conditions for the maize cob bioreactor in the removal of nitrates are at 22 cm substrate column height, small substrate particles and an HRT of 48 h at this point 24 ± 0.3 mg/L of nitrate was recorded. The 22 cm substrate column height for large maize cob particle at 60 h HRT is the second best operating condition since the effluent contained only 26 ± 0.6 mg/L. Similar to the woodchips, at constant HRT and substrate column height, the small particle bioreactors have a better efficiency than that of the large particle size bioreactor at constant HTRs.

(c) Nitrate Removal by Sugarcane Bagasse

Fig. 3 shows the results of nitrate removal by sugarcane bagasse. Similar to maize cobs, the efficient operating condition for the removal of nitrates was at 22 cm substrate column height for the small substrate particles size, at 48 h HRT as illustrated in Fig. 3. At this point the effluent had 27 ± 5 mg/L of nitrate from the initial of 208 ± 0.4 mg/L. Unlike the woodchips, the maize cobs and sugarcane bagasse had only one suitable operating condition.
From the graphs in Figs. 1-3, it can be seen that the mean value of nitrates recorded at the different contact time shows that the performance of the bioreactors in the removal of nitrates increases with the increase in the time of contact and the depth of substrate for all the three bioreactors. The presence of nitrate in the effluent at 12 h was higher than the level recorded at subsequent hours of 24, 48 and 60 h for all the three substrates.

The percentage conversion of nitrate to nitrogen in water increases with increase in the contact of the water with the nitrifying microorganisms [13]. Hence, increase in the contact time increases the efficiency of the bioreactor in the removal of nitrates. Therefore, at 12 h the microorganisms were still growing and hence the rate of nitrate removal was low. The sudden increase in the rate of removal between 12 h and 48 h is attributed to the ballooning population leading to high rate of microbial action.

A comparison of the most efficient operating condition mentioned above (maize cobs and sugarcane at 22 cm small particles and woodchips at 22 cm small and large particles) was done to determine the most efficient substrate and operating condition in the removal of nitrate as shown in Fig. 4.

Fig. 4 shows that woodchips are the most efficient substrate in the removal of nitrates in both bioreactors containing the small particle sizes at the HRT of 48 h the results obtained were as follows: 27 ± 0.5 mg/L and 24 ± 0.6 mg/L of sugarcane and maize cobs respectively and 43 ± 0.5 mg/L and 15 ± 0.5 mg/L in the large and small woodchip bioreactors respectively. Wood chip bioreactors can achieve 80%-100% nitrate removal from wastewater [8]. By keeping other operation conditions constant (substrate height and contact time) and manipulating only the substrate particle size (large particles greater than 4 inches and small particles less than 1 inch) the result shows that the small particle bioreactor had a better performance in the removal of nitrates than the large particle bioreactor for all the three substrates. This means that the performance of small substrate particle bioreactors is better than the performance of bioreactors with large substrate particles. Schipper, et al. [14] state that the wider the surface area in contact with the wastewater the more efficient the system is in the removal of nitrogen species.

3.1.2 Nitrites

The effluent was tested for nitrites at each level of operating condition and the results were recorded. The data were analyzed and the mean values were used to generate the following graphs listed as Figs. 5-7.

(a) Nitrite Removal by Woodchips

The analysis of nitrite removal by woodchips was recorded and plotted as shown in Fig. 5.
From Fig. 5 it was concluded that the rate of nitrite removal by woodchips was achieved by an HRT of 24 h at all the column heights and particle sizes. At 12 h, the operation condition of 22 cm substrate column height of both large and small woodchip particles is less than 5 ± 0.5 mg/L. The 18 cm and 14 cm column heights of both large and small woodchip particles get to less than 1 ± 0.5 mg/L at 18 h and 24 h HRT respectively.

(b) Nitrite Removal by Maize Cobs

Fig. 6 shows the results obtained from the lab analysis of nitrite removal using maize cobs. Similar to woodchips, the rate of nitrite removal increases with increase in the HRT. By an HRT of 24 h, most of the nitrite was removed from the wastewater. And 22 cm column height of small substrate particle sizes was the most efficient, by an HRT of 12 h the value of nitrite recorded was 4.6 ± 0.5 mg/L. Although it achieves the minimum acceptable efficiency earlier than woodchips in nitrite removal the best operating condition of the maize cob bioreactor in the removal of nitrite is at 24 h 18 cm large particles, which yields a result less than 1 ± 0.5 mg/L of nitrite. This is due to the rapid development of microorganism due to its filamentous structure and high intercob void [14]. Unlike the nitrites, it takes longer to achieve the desired efficiency for nitrate removal which is the contaminant in highest quantities.

(c) Nitrite Removal by Sugarcane

The results were plotted into a graph in Fig. 7 to show the performance of sugarcane bagasse in the removal of nitrites. From the graphs in Fig. 7, it was noted that the mean values of nitrites present in the effluent were reducing at a high rate with increase in the contact time. Similar to the other substrates, the required level of nitrite was achieved by the HRT of 24 h for all the substrates column heights. At 22 cm substrate column height for the small substrate particle size at an HRT of 24 h, the result obtained was 2.1 ± 0.5 mg/L of nitrite.

For all the three substrates, the mean values of nitrite present in the effluent at 24 h were less than the required level of 10 mg/L. For both large and small substrate particle size bioreactors, the efficiency of each substrate in the removal of nitrite was very high with minimum values achieved at the second level of contact time (24 h). Therefore, from these experiments, 90% of the mean values of nitrites were considerably low. The same outcome was observed by Lepine, et al. [11] where it was concluded that between 12 and 24 h HRT the rate of conversion of nitrite to nitrate was maximum. They also concluded that the levels of nitrites present are 1%-2% of the nitrates present, indicating that the values of nitrites will always be
lower than that of nitrates. The performance of the small particle size bioreactor was compared to the performance of the large particle size bioreactors at constant height and time. Fig. 8 shows the variation in the mean values of nitrites in the effluent at different operating conditions.

Fig. 8 below shows the negative gradient of the trend line for the means of nitrite in the effluent from both small and large particle size bioreactor. This means that the values of nitrites in the effluent decrease with increase in contact time from 12 h to 60 h and increase in substrate height from 14 cm to 22 cm. In the same Fig. 8, the results show that there is minimal variation of efficiency in removal of nitrites with bioreactors of varied substrate particle size. This is because the nitrites are easily converted to nitrates by the denitrifying bacteria. For this reason, the nitrites are not a suitable parameter to determine the performance of the bioreactors.

3.1.3 Phosphate Analysis

The effluent was tested for phosphate and the mean values of three replicates were used in developing following graphs listed in Figs. 9-11.

(a) Phosphate Removal by Woodchips

Fig. 9 shows the comparison of the different operating conditions in the removal of phosphates by woodchips. The results in Fig. 9 show that at 22 cm substrate column height, both the large and small woodchips bioreactors had high phosphate removal rates. For both large and small particle bioreactors, an HRT of 24 h was enough to achieve 5.7 ± 0.08 mg/L and 4.77 ± 0.05 mg/L respectively at 22 cm substrate column height. However, the small woodchip bioreactors were slightly more efficient than the large woodchip bioreactor at an HRT less than 24 h. For the 22 cm substrate column height the range of the mean values of the large and small substrate size at 12 h was 5.1 mg/L, and 1.03 mg/L and 0.8 mg/L for the 24 h and 48 h respectively.

(b) Phosphate Removal by Maize Cobs

The results for the removal of phosphate by maize cob bioreactors are illustrated in the graph in Fig. 10, the 22 cm substrate column height of small maize cob particles was the most efficient in the removal of phosphates. The efficiency of all the operating conditions increases after an HRT of 24 h. The optimal operating condition for the maize cob bioreactor is 22 cm substrate column height for the small maize cob particles at an HRT of 24 h yielding 4.3 ± 0.5 mg/L.
The other conditions do not yield the desired results of less than 5 mg/L unless it is subjected to an HRT 60 h.

(c) Phosphate Removal by Sugarcane

The results showing the analysis of phosphate removal by sugarcane bagasse are illustrated in the graph in Fig. 11.

From Figs. 9-11, it is evident that the performance of the bioreactors increases with increase in the time of contact from 12 h to 60 h for all the three substrates. At maximum height of 22 cm for all the three substrates the bioreactors had the highest performance, corresponding to a removal rate of phosphate. Fig. 12 shows the comparison of the three substrates at the operating condition of 22 cm substrate column height, small substrate particle sizes.

From Fig. 12, woodchips are the most efficient in the removal of phosphates, maize cobs are slightly more suitable than sugarcane bagasse. For woodchips, the desired outcome is achieved by the HRT of 24 h where the result is $4.7 \pm 0.5$ mg/L. For maize cobs and sugarcane bagasse, the desired outcome is achieved by 48 h HRT: the phosphate present was $4.3 \pm 0.5$ mg/L and $4.1 \pm 0.5$ mg/L. This means that the substrate with the highest carbon content has the potential of removing more phosphate pollutants. According to Kaetzl, et al. [12], to increase the efficiency of bagasse in the removal of phosphate, it requires chemical modification such as pretreatment of the sugarcane to make its chemical structure more adsorptive to phosphates.

4. Analysis of the Performance of Each Substrate

The performance of the different substrates (woodchips, maize cobs and sugarcane bagasse) was tested at the different operating conditions of contact time (12 h, 24 h, 48 h and 60 h), height (14 cm, 18 cm and 22 cm) of substrate and particle sizes (small and large). Nitrites are the parameter that was preferred to determine the suitable operating conditions of the bioreactors since nitrite recorded very low values and the desired quantity for both nitrites and phosphates were easily achieved compared to nitrates. The mean
values of nitrates were used in calculating the efficiency from Eq. (2).

\[ e\% = \frac{(x - y)}{x} \times 100 \]  

where:
- \( x \) = contaminant in the raw water (mg/L);
- \( y \) = experimental value (mg/L).

The required efficiency for the removal of each contaminant was calculated using the desired minimum values as listed in the constitutional standards of effluent before discharge and the efficiencies were shown in Table 2.

The percentage efficiency for each bioreactor in the removal of each substrate at a given operating condition was tabulated and the result recorded. The results in the bar charts were compared with that of Table 2 to be able to identify the most suitable operating conditions that can achieve the required efficiency of 95% for nitrate removal and in the process achieve the removal of nitrites and phosphate to meet the desired efficiency of 60% and 50% respectively.

### 4.1 Woodchips

The efficiency of woodchips was calculated using the mean values of nitrates, nitrites and phosphates obtained in Figs. 1, 5 and 9 respectively. From the graphs, the optimal operating conditions of the small wood chip bioreactor in the removal of all the parameters were at 22 cm 48 h and 18 cm 60 h or 22 cm 60 h for the large woodchip bioreactor. At these operating conditions, the efficiency of these three conditions was then calculated using mean nitrate values as shown in Table 3.

Two of these three operating conditions give the desired efficiencies. According to Lepine, et al. [11], the efficiency of wood chip bioreactor increases with increase in the HRT. This is because the lignin and cellulose in the woodchip structure do not decompose at a high rate hence it is not depleted easily. These properties make woodchip a suitable substrate in a bioreactor.

### 4.2 Maize Cobs

The efficiency of maize cobs was calculated and presented in Table 4. For both the large and small particles bioreactors the optimal operating condition in the maize cob bioreactor was 22 cm substrate column height at the HRT of 48 h for small maize cob particles and 22 cm substrate column height at the HRT of 60 h for the large maize cob particles. The efficiency was calculated based on the information.

From Table 4, the efficiency of the maize cob bioreactor increases with increase in the column height and the contact time. Schipper, et al. [14] had similar results and concluded that the maize cobs in bioreactors require a large surface area and longer HRT to increase its efficiency although in his study, it was used for the removal of dye.

In another experiment maize cobs have been used in the removal of metallic ions such as lead, copper and nickel from wastewater and the particle size and HRT were major factors in the efficiency of the wastewater treatment system. Therefore, the efficiency of a maize cob bioreactor relies on longer HRT and increased surface to volume ration of the substrates.

### 4.3 Sugarcane Bagasse

The efficiency values for the sugarcane bioreactor were calculated and tabulated in Table 5 at the optimal conditions for operation which were 48 h and 60 h at

| Substrate  | Equation | Efficiency (%) |
|------------|----------|----------------|
| Nitrate    | (210-10)/210 | 95 |
| Nitrite    | (25-10)/25 | 60 |
| Phosphate  | (21-10)/21 | 50 |

| Table 3 Efficiency values for optimal conditions in woodchip bioreactor. |
|----------------|----------------|
| Operating condition | Mean nitrate values | Efficiency |
| 22 cm 48 h small wood chips | 12 ± 0.5 mg/L | 94% |
| 18 cm 60 h small woodchips | 21 ±0.5 mg/L | 89% |
| 22 cm 60 h large woodchip | 17 ± 0.5 mg/L | 93% |

| Table 2 Required efficiency for the removal of contaminants. |
|----------------|----------------|
| Substrate  | Equation | Efficiency (%) |
| Nitrate    | (210-10)/210 | 95 |
| Nitrite    | (25-10)/25 | 60 |
| Phosphate  | (21-10)/21 | 50 |
Table 4  Efficiency values for optimal conditions in maize bioreactor.

| Operating condition                  | Mean nitrate values | Efficiency |
|---------------------------------------|---------------------|------------|
| 22 cm 48 h small maize cobs           | 21 ± 0.5 mg/L       | 90%        |
| 22 cm 60 h the large maize cobs       | 24 ± 0.5 mg/L       | 88%        |
| 22 cm 60 h the small maize cobs       | 18 ± 0.5 mg/L       | 92%        |

Table 5  Efficiency values for optimal conditions in sugarcane bagasse bioreactor.

| Operating condition                  | Mean nitrate values | Efficiency |
|---------------------------------------|---------------------|------------|
| 22 cm 48 h small sugarcane            | 20 ± 0.5 mg/L       | 90%        |
| 22 cm 60 h the large sugarcane         | 27 ± 0.5 mg/L       | 87%        |
| 22 cm 60 h the small sugarcane         | 13 ± 0.5 mg/L       | 92%        |

22 cm height in small substrate particles bioreactors, and 22 cm substrate column height for the large particle size at 60 h HRT.

5. Conclusion

The most suitable substrate in the removal of contaminants is the woodchips. The efficiency of woodchips was highest at 94%, 89% and 93% efficiency in the removal of nitrates at 22 cm substrate column height at HRT of 48 h for small substrate particle size, 18 cm substrate column height at HRT of 60 h for small substrate particle size and 22 cm substrate column height at HRT of 60 h for large substrate particle size.

The best design operation condition for the aquatic wastewater treatment trickling filter for the removal for nitrates, nitrates and phosphates was at 18 cm and 22 cm substrate column height for the small and large woodchip particles at 48 and 60 h HRT respectively. For maize cobs and sugarcane bagasse, the optimal conditions were at 22 cm substrate column height at 60 h HRT for small particle size.

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