PERFORMANCE AND SHORT TERM DURABILITY OF PALM KERNEL SHELL AS A SUBSTRATE MATERIAL IN A PILOT HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLAND TREATING SLAUGHTERHOUSE WASTEWATER

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Abstract. Wastewater treatment using constructed wetlands is one of the effective and low-cost technologies to improve the quality of slaughterhouse effluent. This study was carried out to investigate the suitability of palm kernel shell as a substrate material for constructed wetlands treating slaughterhouse wastewater. Rhizomes of \textit{Thalia Geniculata} and \textit{Typha Latifolia} were grown in four pilot horizontal subsurface flow constructed wetland beds filled with palm kernel shell and grave, and their growth and treatment performance evaluated. The results of the study showed that \textit{Thalia Geniculata} survives and proliferates in palm kernel shell bed. The mean removal rates of 72.81\% (BOD\textsubscript{5}), 89.87\% (TSS), 39.42\% (NH\textsubscript{4}-N), 60.79\% (NO\textsubscript{3}-N) and 42.52\% (PO\textsubscript{4}) for the palm kernel shell were comparable to the values obtained for the gravel bed. The study proved that palm kernel shell, as a substrate material in constructed wetlands had the potentials to sustain the growth of some macrophytes, as well as the capacity to remove contaminants from wastewater.

Keywords: constructed wetland, macrophyte, palm kernel shell, slaughterhouse, wastewater treatment.

Introduction

Effluent from slaughterhouses have been recognized as one of the leading pollutants of surface and underground water (Okoye \textit{et al.}, 2018) and treatment of slaughterhouse effluent prior to discharge has become imperative, in order to mitigate its environmental impact and also to safeguard the users of the receiving environment. Natural treatment systems such as constructed wetlands have been recommended for wastewater treatment, especially in developing countries where a combination of factors hinders the use of more sensitive and expensive technologies (Badejo \textit{et al.}, 2012).

Subsurface flow constructed wetlands offers additional advantages of minimization of pest and odour problems and possibly a greater assimilation potential per unit of land surface. As the water surface is not visible, problems with public access are minimal (USEPA, 1999). However, a key construction material that strongly influences the installation costs of subsurface flow constructed wetlands is the substrate material. The cost of gravels often represented 50\% of the building cost of constructed wetlands (USEPA, 1999), thus there is need to develop and use cheaper materials. The use of agricultural by-products as substrates in constructed wetlands have been be evaluated (Tee \textit{et al.}, 2009; Cameron, Schipper, 2010; Nguyen \textit{et al.}, 2013).

The motivation for the use of agricultural byproduct is the fact that the cheapest substrates would be the unwanted ones. A previous study on the physical and chemical properties of Palm Kernel Shell (PKS) suggests they could be a suitable substrate in constructed wetlands (Chong \textit{et al.}, 2009). Jong and Tang (2015) incorporated PKS as part of the substrate in a vertical flow constructed wetland for septage treatment and reported nitrogen removal of 91\%, compared to 95\% obtained for sand substratre.

However, the use of PKS as a wetland substrate has been scantily researched. Nigeria is presently the fifth largest oil palm producing nation, accounting for 1.5\% of the global output (Izah, Ohimain, 2016). The total area for oil palm in Nigeria was estimated at 3,053,974 hectares (FAO, 2018) and approximately 15 to 18 tonnes of fresh fruit bunches are produced per hectare per year, with PKS making up about 64\% of the bunch mass (Okoroigwe \textit{et al.}, 2014). This has created a serious environmental challenge of PKS disposal. Thus replacing expensive gravels with this industrial by-product may not only lead to a substantial reduction of costs, but also to a beneficial reuse of this potential resource, which is in...
The pilot horizontal subsurface flow constructed wetlands were set up in the grounds of the Agulu slaughterhouse. Agulu, which falls within the Awka Capital Territory, is one of the most populous towns in Anambra State, Nigeria. It lies within latitudes 6.04 °N and 6.09 °N and longitudes 7.00 °E and 7.03 °E. Four rectangle shaped wetland cells (0.5 × 0.3 × 0.35 m) made of transparent plastic were constructed in the field. Two cells were filled with gravel and the other two were filled with PKS of size >5mm. Five healthy mature plants of Thalia Geniculata and Typha Latifolia uprooted from natural wetlands in the study area and the above-ground portion cut at a height of 0.5m, were planted in the wetland cells. After planting, all the cells were filled with stream water to enable the plants acclimatize for 2 weeks, after which the plants were left to establish in wastewater for 10 weeks. Pre-settled slaughterhouse wastewater was fed to the cells on a batch mode with retention time set at 14days.

Influent and effluent sampling were carried out from August 2016 to February 2017. Grab samples were collected every 2 weeks, using 500 ml plastic containers washed in non-ionic detergent and rinsed with tap water prior to usage. During sampling, field measurements were first carried out; the plastic containers were then rinsed with sample wastewater three times and filled to the brim. The samples were immediately transported to the laboratory in an ice block filled cooler and stored in the refrigerator at about 4°C prior to analysis.

Nitrate nitrogen (NO₃-N) and orthophosphate (PO₄³⁻) were analyzed using the USEPA approved general purpose field test kits by Hach Company (USEPA, 2016). Biochemical oxygen demand (BOD₅), total suspended Solids (TSS) and ammonium nitrogen (NH₄-N) were analyzed according to standard methods (APHA, 1998).

Plant growth was monitored by measuring the height and abundance in each cell. Shoot heights (from base to apex) of 5 tallest plants in each cell and standing shoot were measured every two weeks. All cells were harvested in November 2016 after 6 months growth. Plants were cut at the media surface. The harvested above-ground biomass were cut into fractions of 15 cm in length and dried at 100 °C for 24 hours before weighing to determine the dry weight.

The physical and mechanical properties of the PKS used in the pilot wetland cells were evaluated to determine their short-term durability. This was done at the beginning of the pilot study (May 2016), after 6 months of operation (November 2016), and finally after 20 months of operation (January 2018). The physical properties measured were the specific gravity and aggregate thickness, while aggregate crushing value was the only mechanical property measured.

The differences in the mass removal rates of the cells were analysed with the one-way analysis of variance (ANOVA).

Results and Discussion

Macrophyte growth in PKS

After three weeks of planting the macrophytes in the pilot wetlands, the Typha Latifolia planted in PKS were observed to be wilted and by the third week they were dead. This death can be due to the presence of residual palm oil in the pilot PKS wetland cell, as was also observed by Chong et al. (2009) for some other macrophytes planted in PKS. Whereas the Typha Latifolia in gravel had grown to a height of 0.5 m as shown in figure 1. So the study on the feasibility of PKS as substrate was limited to pilot wetland cell planted with Thalia Geniculata which showed very good resistance to the effects of residual palm oil in the PKS cell.

Fig. 1. Pilot wetland cells with PKS and gravel as substrates: A) Typha Latifolia after planting in PKS; B) Typha Latifolia after three weeks in PKS; C) Typha Latifolia after three weeks in gravel.
Prior to the experimental treatments, the *Thalia Geniculata* had grown into thick vegetation. Increase in shoot height was faster in the gravel cell than in PKS with plants attaining maximum heights of 1.4 m and 1.1 m respectively within 3 months of establishment. The variation in plant heights during the study period is shown in figure 2.

Fig. 2. Variation in shoot heights in the gravel and PKS media during the experimental period. Shoots were harvested in November 2016 giving way to new growth.

The difference in height of the macrophytes in the gravel and those in PKS after three months of establishment can be clearly seen in figure 3.

Fig. 3. Difference in height of the *Thalia Geniculata* in gravel and PKS substrate after three months of establishment

From a density of 28.6 shoots/m² at start of the study, 97.1 shoots/m² was obtained after 3 months of establishment for the gravel substrate and 62.9 shoots/m² for the PKS substrate (Fig. 4).

The results of the study showed that the height of plants was influenced by the type of substrate used, which is in line with the submissions of Chong *et al.* (2009) who stated that the height of macrophytes were affected by the micro-ecosystem of their substrate. However, their observation of higher plant growth in PKS than in gravel was contrary to the findings of this study with increased height in the gravel than the PKS substrate. The mean difference between the shoot densities of *Thalia Geniculata* in gravel and PKS was not significant ($p = 0.92$).

Fig. 4. Variation in shoot density in the gravel and PKS during the study period. Shoots were harvested in November 2016 giving way to new growth.

Slower rate of increase in abundance of plants in the PKS substrate can be attributed to the effects of residual palm oil in the cell, which cleared with the batch loading of wastewater resulting in higher abundance towards the harvest period. Chong *et al.* (2009) also reported that PKS based microcosm gave a higher shoot generation rate than gravel. Higher dry biomass yield obtained for PKS substrate was consistent with the findings of Chong *et al.* (2009) who reported that the rate of dry biomass gain was dependent on the medium in the microcosm and the stage of plant growth, and that biomass gain in the PKS based microcosm was higher with an average rate of 4.4 kg dry biomass/m² as against the 3 kg dry biomass/m² for the gravel based media. Abundance increased with time following batch feeding with slaughterhouse wastewater. Prior to harvest, the abundance in the PKS had surpassed that of gravel with values of 245.7 shoots/m² and 211.4 shoots/m² respectively. The value of the above-ground biomass yield for *Thalia Geniculata* in the PKS cell was 4.72 kg dry biomass/m². The value was a little higher than the biomass yield of 4.57 kg dry biomass/m² obtained for the *Thalia Geniculata* in gravel.

*Treatment performance of PKS and gravel cells*

The average mass removal efficiencies of the gravel and PKS beds are presented in table 1

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Gravel</th>
<th>PKS</th>
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<tbody>
<tr>
<td>BOD$_5$</td>
<td>75.42</td>
<td>72.81</td>
</tr>
<tr>
<td>TSS</td>
<td>89.87</td>
<td>88.18</td>
</tr>
<tr>
<td>NH$_4$-N</td>
<td>39.42</td>
<td>41.33</td>
</tr>
<tr>
<td>NO$_3$-N</td>
<td>60.79</td>
<td>55.86</td>
</tr>
<tr>
<td>PO$_4$&lt;sup&gt;3-&lt;/sup&gt;</td>
<td>42.52</td>
<td>44.73</td>
</tr>
</tbody>
</table>

The mass removal rates are shown in Figures 5 to 9.
The performance of the cells in terms of organic matter removal was satisfactory with more than 70% reduction in both PKS and gravel beds. Although the gravel bed had a higher mean BOD removal efficiency than the PKS bed, the difference between them was not statistically significant \((p = 0.331)\). The PKS media being an organic substrate could potentially release soluble organic matter into the bed effluent, thereby increasing the BOD content in the outflow water, leading to a higher value than the gravel bed. The slightly lower removal rate obtained for the PKS bed can also be attributed to the expected lower dissolved oxygen concentration as presence of PKS results to an additional oxygen consumption which creates more anaerobic microsites that may inhibit the biodegradation of carbonaceous compound by aerobic microorganisms.

The mean percentage TSS mass removal of the PKS and gravel beds were not significantly different \((p = 0.410)\). Both beds demonstrated comparable filterability, attaining similarly high removal of suspended solids irrespective of the substrate material. The resulting effluent from the beds were evidently clearer and free of visible suspended matter upon exit from the wetlands, which may be attributed to the fact that TSS removal takes place through physical processes. Generally, higher NH\(_4\)-N removal efficiency was found in the gravel beds compared to the PKS bed. However, no statistically significant difference \((p = 0.465)\) was found with the NH\(_4\)-N treatment efficiencies between the two beds. The higher mean mass removal rate obtained for the gravel bed can be attributed to the likely higher dissolved oxygen content in the bed. Nitrification is heavily dependent on the presence of dissolved oxygen. The condition in the PKS bed is likely to be more anaerobic than aerobic. PKS as an additional carbon source, which is known to contributed to greater growth and biomass of heterotrophs did not significantly influence the ammonia removal efficiencies, which can be attributed to the fact that ammonia oxidisers compete poorly with aerobic heterotrophic microorganisms (Vymazal, 2007).

Higher NO\(_3\)-N mass removal efficiency was obtained in the PKS bed compared to the gravel bed indicating the superiority of the PKS bed over the gravel bed in
terms of NO$_3$-N reduction, although the result was not statistically significant ($p = 0.107$). According to Horne (1995), denitrification can be induced with oxygen levels less than 0.2 mg/l, a sufficient supply of nitrate and carbon food, and the presence of a physical site where the bacteria required in the process can attach to. PKS acted as additional carbon source to support denitrification and also, the expected lower dissolved oxygen concentration in the PKS bed as a results of additional oxygen consumption by the organic media, must have created more anaerobic microsites which is regarded as a determining factor for NO$_3$-N removal. Higher PO$_4^{3-}$ mass removal efficiency was initially recorded for the gravel bed compared PKS bed. However, saturation of removal routes in the gravel bed, which led to PO$_4^{3-}$ release, was not observed in the PKS bed, which indicated that its removal routes had not been saturated. Also the difference in the mean removal efficiencies of both systems were found not to be statistically significant ($p = 0.790$). The overall performance of the PKS bed as regards pollutant removal from slaughterhouse wastewater was satisfactory when compared to the gravel media. This is in line with the conclusions of Chong et al. (2009) that PKS performed better than the conventional constructed wetland medium and therefore it is a better medium for constructed wetland application.

The durability of an aggregate is a measure of its resistance to wear, moisture penetration, decay and disintegration (Olanipekun et al., 2006). The durability of the PKS in pilot HSSF CW was evaluated over 20 months operational period, by determining three main properties as shown in Table 2.

**Table 2. Variation in physical and mechanical properties of PKS**

<table>
<thead>
<tr>
<th>Properties</th>
<th>May 2016</th>
<th>November 2016</th>
<th>January 2018</th>
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<tbody>
<tr>
<td>Specific gravity</td>
<td>1.34</td>
<td>1.28</td>
<td>0.96</td>
</tr>
<tr>
<td>Shell thickness, mm</td>
<td>4.70 ± 0.19</td>
<td>4.67 ± 0.17</td>
<td>4.64 ± 0.19</td>
</tr>
<tr>
<td>Aggregate crushing value, %</td>
<td>5.3</td>
<td>8.7</td>
<td>14.9</td>
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The test results show that the specific gravity obtained for the PKS at the start of the experiment was 1.34 compared to the typical value of 2.65 for granite aggregate. After 6 month in the pilot HSSF CW, the specific gravity reduced slightly to 1.28. However, after 20 months in the system, there was a significant reduction in the specific gravity to a value of 0.96. Similar trend were observed for aggregate crushing values. The aggregate crushing value, which is the relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load, was 5.3% at the start of the experiment in May 2016. The value obtained for the PKS was lower than the typical range of 24-26% for granite aggregates, which shows that palm kernel shell aggregates are stronger under loads than the normal weight aggregates. The aggregate crushing value of the PKS increased to 8.7% and 14.9% after 6 and 20 months in the HSSF CW.

There was no significant variation in the mean shell thickness over the 20 months of operation. The mean thickness of the selected shells at the start of the experiment was 4.70 mm and reduced slightly to 4.64 mm after 20 months in the HSSF CW. PKS has been used for different purposes in the construction industry because of its relative abundance and certain properties such as high compaction, low density and strong interlocking properties (Amu et al., 2008). Okorogiwe et al. (2014) stated that some characteristics of PKS support its application as both construction material filler and water treatment agent in the food and beverage industry.

However, the results of this study have shown that PKS, being a biodegradable material is subject to considerable deterioration over time. Therefore, further studies to investigate the strength and durability of PKS as a constructed wetland substrate is recommended.

**Conclusions**

The use of PKS as a wetland substrate revealed satisfactory organic matter, nutrient and suspended solids removal, comparable to the levels achieved with the conventional gravel substrate. *Thalia geniculata* plant survives and proliferates in minimally washed PKS, although with negative effects on the height and shoot generation rate. PKS was proven to elevate the denitrification process by effectively functioning as an additional carbon supplier. The study concludes that slaughterhouse wastewater treatment by constructed wetland with locally available macrophyte and PKS as substrate is favourable under Nigeria’s climatic conditions.

**References**


