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Greywater Treatment Using Activated Biochar Produced from Agricultural Waste

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***Abstract*—**The increase in urbanisation in South Africa has led to an increase in water demand and a decline in freshwater supply. Despite this, poor water usage is still a major challenge in South Africa, for instance, freshwater is still used for non-drinking applications. The freshwater shortage can be alleviated by using other sources of water for non-portable purposes such as greywater treated with activated biochar produced from agricultural waste. The success of activated biochar produced from agricultural waste to treat greywater can be both economically and environmentally beneficial. Greywater treated with activated biochar produced from agricultural waste is considered a cost-effective wastewater treatment. This work was aimed at determining the ability of activated biochar to remove Total Suspended Solids (TSS), Ammonium (NH_4-N), Nitrate (NO_3-N), and Chemical Oxygen Demand (COD) from greywater. The experiments were carried out in 800 ml laboratory plastic cylinders used as filter columns. 2.5 cm layer of gravel was used at the bottom and top of the column to sandwich the activated biochar material. Activated biochar (200 g and 400 g) was loaded in a column and used as a filter medium for greywater. Samples were collected after a week and sent for analysis. Four types of greywater were treated: Kitchen, floor cleaning water, shower and laundry water. The findings showed: 95% removal of TSS, 76% of NO_3-N and 63% of COD on kitchen greywater and 85% removal of NH_4-N on bathroom greywater, as highest removal of efficiency of the studied pollutants. The results showed that activated biochar produced from agricultural waste reduces a certain amount of pollutants from greywater. The results also indicated the ability of activated biochar to treat greywater for onsite non-potable reuse purposes.

***Keywords*—**Activated biochar produced from agriculture waste, ammonium (NH_4-N), chemical oxygen demand (COD), greywater, nitrate (NO_3-N), total suspended solids (TSS).

I. Introduction

WATER is a necessity for the social and economic development of human beings and the preservation of a clean environment [1]. World Health Organization estimated that about 1.2 billion people are facing physical water shortage, one-quarter of the world population is facing economic water shortage [2] in total 62% of the world population will face water scarcity by 2030 [3]. The world population is growing in particular in urban areas and developing countries [2] which led to the increase in freshwater demand essential for socio-economic development. The production of wastewater is increasing with the increase of population, and this has made the wastewater and greywater reliable sources of water to withstand the increasing demand of freshwater when effectively treated and suitably reused [4], [5].

Researches emanated from various ways of saving freshwater, improvement of living standard, agricultural expansion and finding cost-effective methods of greywater treatment and reused [2]. Wastewater and greywater recycling is emerging as an integral part of water demand management, promoting the preservation of high-quality freshwater as well as reducing pollutants in the environment and reducing overall supply costs [6], [7]. Greywater is defined as household wastewater discharged, excluding blackwater (toilet water), therefore, greywater consists of water from showers, sinks, laundry, bath, kitchen and dishwashers. Greywater makes up the largest proportion of the total wastewater flow from households [5], [8]-[10]. It accounts for approximately 50-80% of the household's total wastewater. Greywater from showers, bathtubs and hand wash basins is less polluted, and can be directly reused without any pretreatment, the treated greywater can be used for car wash, toilet flushing and irrigation [7], [11]-[13].

Literature has indicated that 27% of greywater comes from kitchen sink and dishwasher, 47% originates from the wash basin, bathroom, and shower, and 26% originates from laundry and the washing machine [14]. According to Jeppesen [15], laundry and bathroom effluents are technically possible to be reused without treatment. Critical parameters to consider for the sustainability of greywater reuse are pH, electrical conductivity, suspended solids, heavy metals, faecal coliforms, *Escherichia coli*, and dissolved oxygen, biological and COD, total nitrogen and total phosphorus [2], [16]. The reduction of organic matter level in greywater is expressed as COD, and it is between 13 and 8000 mg/l and is expected to be almost similar to household wastewater – which includes the waste from the toilet [2]. As demonstrated, the chemical, physical and microbiological characteristics of greywater are quite inconstant among households due to the type of detergents used, type of things being washed, the lifestyle of occupants and other practices followed at household levels [17]. Generally, domestic wastewater contains 50 to 100 mg/L oils and greases, for which greywater is the main contributor, approximated to two third [18]. Increasingly, greywater reuse is seen as an essential component of local and national efforts to adapt to climate change, enhance food security, extend potable water supply, and reduce pollutants in the environment [19].

Greywater treatments are classified based on the treatment principle and are divided into physical, chemical, and

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biological [21]-[23]. Greywater treatment generally includes the above technologies followed by pretreatment and disinfection mainly with chlorine [21], UV radiation has been used for disinfection with excellent results [24]. Coarse sand is mainly used for physical greywater treatment; soil and membrane filtrations are also used in physical processes. This treatment considerably reduces the organic matters and concentrations of faecal bacteria [25].

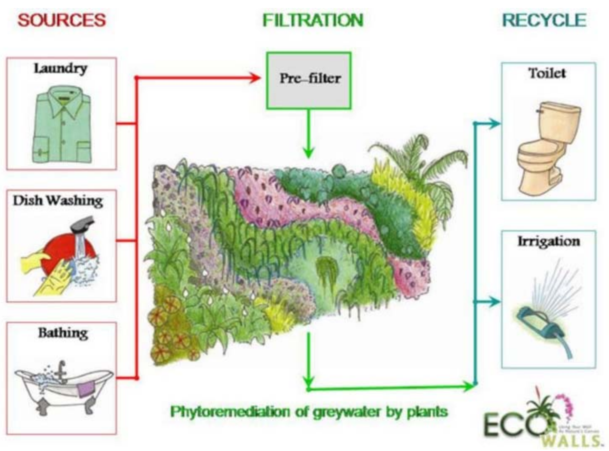

Fig. 1 Phytoremediation - green plants are used for greywater treatment purpose [20]

The physical treatment produces a bright and odourless effluent, which can be stored for several days without the need for disinfection. The physical treatment is used for as a pre-treatment method before biological or chemical or post-pretreatment [21]-[23]. The application of chemical processes reduces organic substances and turbidity, chemical processes alone are not effective to meet potable water standards [21], [23]. This is achieved but adding chemical such as coagulants and flocculants [26]. The biological method is mainly used for dark greywater treatment, but a disinfection stage is required for low pathogen effluent [23]. Some examples are sand filter, horizontal-flow constructed wetland (HFCW), vertical-flow constructed wetland (VFCW), anaerobic filters, and vertical-flow filter (VFF) [23]. These systems are a combination of physical processes such as filtration through a filter medium (e.g., gravel, rocks, sand, cinder) with biological processes such as aerobic or anaerobic degradation via microorganisms found within the system [27].

Among the consequences of discharging greywater to the environment is the depletion of oxygen, eutrophication and turbidity in the discharge streams [17]. In rural areas greywater is used for irrigation and is discharged in rivers, this may lead to waterborne diseases [17]. Oxygen and nitrogen nutrients can damage the environment as they lead to oxygen consumption in aquatic systems; the consumption of oxygen has as consequence "dead bottoms" in marine systems. Untreated greywater use for gardening may cause an increase in the soil alkalinity over a long time [29]. Though considered relatively clean, greywater can be quite polluted, and its indiscriminate reuse may represent a risk to public health and the environment. Greywater is, therefore, an essential component of wastewater, and qualitatively studies have shown that there is a significant contribution of this water to the concentration of some pollutants and contaminants in the total wastewater [6], [16].

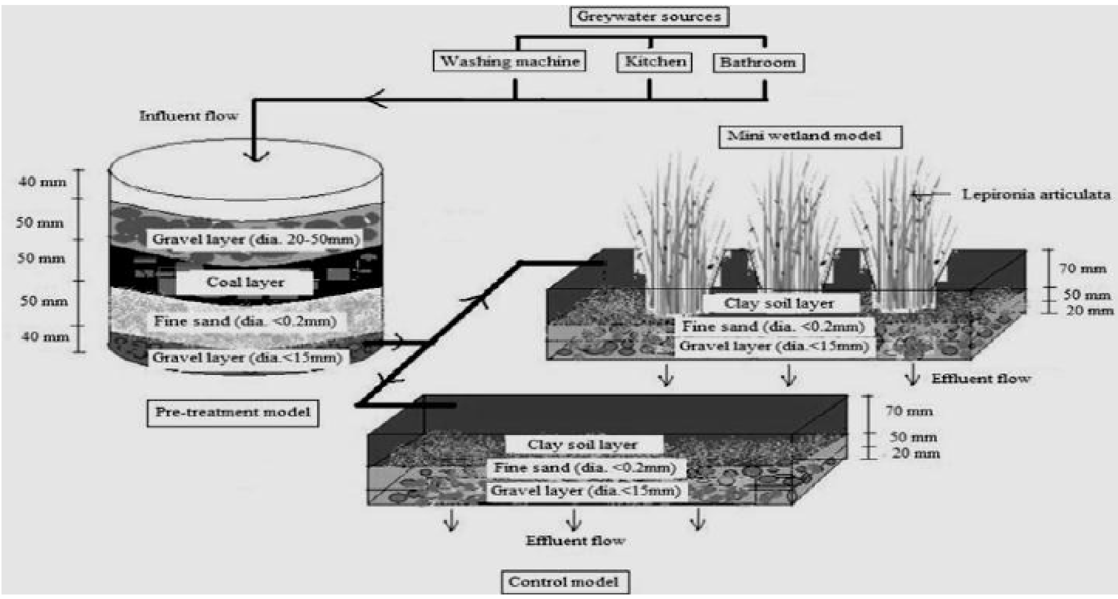

Fig. 2 Schematic diagram of the mini constructed wetland treatment [28]

Greywater systems bring significant savings in fresh drinking water in addition to reducing the amount of generated wastewater, therefore easing the pressure on the environment. Furthermore, reclaimed water often contains some nutrient elements, so its application to the agricultural field may bring additional benefit to soil and crop systems [30]. Treated greywater may be used for irrigation, toilet flushing, outdoor applications, development and preservation of wetland or into ground infiltration [6]. The main target in greywater treatment is the reduction of easily degradable organic compounds responsible for bad odours in the environment [31] and immediate processing and reuse of greywater before anaerobic conditions occur [7]. Greywater treatment with activated biochar produced from agricultural waste can be employed in the filtration step as part of the physicochemical treatment process.

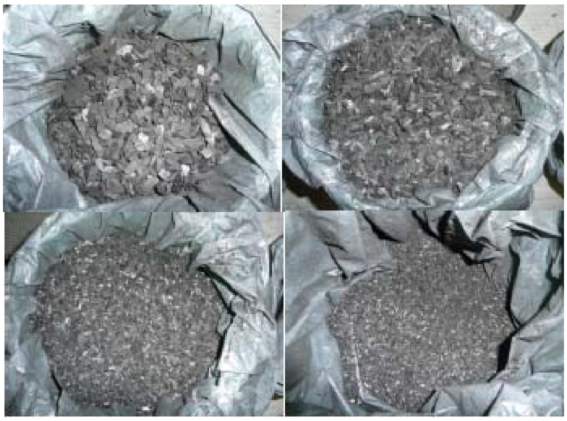

Fig. 3 Biochar with different particle sizes: (>5 mm; 2,8-5 mm; 1,4-2,8 mm and 1-1,4 mm) [32]

Greywater treated with biochar has several potential merits compared to existing low-cost methods (i.e., sand filtration, boiling, solar disinfection, chlorination). Biochar is a low-cost and renewable adsorbent made using readily available biomaterials and skills, making it appropriate for poor communities [33]. Existing methods predominantly remove pathogens, but biochars remove chemical, biological and physical contaminants [34]. Biochars converted from agricultural residues had strong sorption ability to different types of contaminants, pharmaceuticals wastewater, such as Sulfamethoxazole (SMX). Biochar can prevent pharmaceuticals leaching from soil into groundwater as well as improve soil fertility and sequester carbon [33]. Biochar can enhance soil fertility and crop productivity) and reduced emissions of NOx and CH_4 [35]. Biochar produced from secondary forest residuals significantly reduce the leaching of fertiliser N and increase plant growth and nutrition [36], [14]. Land application of biochar could effectively isolate carbon in soils and thus mitigate global warming [35].

Greywater treated with activated biochar is slowly earning its mark as one of the best methods of greywater treatment for non-portable uses. This method helps to prolong, conserve and preserve freshwater supply in countries that have a chronic freshwater shortage. Activated biochar is a cheap method of greywater treatment. The envisage shortage of freshwater supply is going to give greywater a footprint in reuse water supply, as it does not involve expensive chemicals to treat. This work focuses on the removal ability of activated biochar produced from agricultural waste to remove contaminants such as TSS, NH_3-N, NO_3-N and COD from greywater. Four types of greywater namely; kitchen, floor cleaning, shower and laundry greywater were used.

II. Materials and Methods

A. Materials

Four types of greywater used in this work were collected from a house in the Secunda region; these greywaters were kitchen, floor cleaning, shower and laundry greywater. Activated biochar produced from agriculture waste of particle size less than 2.8 mm was kindly donated. Gravel was kindly donated from a construction site.

B. Experiment Setup

The experimental setup consisted of a column filtration medium used to test the removal capacity of the activated biochar from agriculture waste. The column had three layers, 2.5 cm of gravel at the top and the bottom, activated biochar (200 g and 400 g) middle layer. This was packed in 800 ml plastic cylinder as a batch filtration system. An effluent collector was placed at the bottom of the filter column to collect effluent from the individual greywater samples. The greywater was fed at the top of the column as shown in Fig. 4

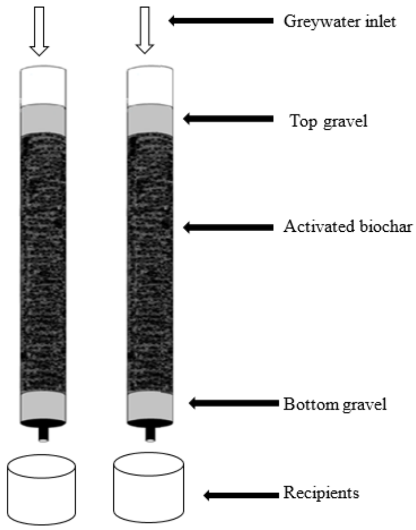

Fig. 4 Experimental setup

C. Experiment Procedure

Greywater samples from kitchen sink, floor cleaning, shower and laundry were collected from a house once a week for four weeks and feed in the designed filter columns as seen in Fig. 4. The experiments were performed using the two different biochar loading. The experiments were done by individually injecting greywater samples one after another into the filter columns. When injecting greywater into the column, distribution (spraying) of greywater was ensured to make it a point that all the filter material are covered (activated biochar and gravel). The experiments were run at the room temperature, 20 ^{o}C. The gravitational flow of greywater from the top to the bottom of the filter column was observed though the flow was low due to the size of some activated biochar. The samples at the bottom of the column filter were collected after a week. The original water samples were collected together with the treated greywater and kept in the fridge at 4 °C for analysis. The effluent greywater from activated biochar was analysed for pH, Electrical Conductivity (EC), TSS, NH4-N, NO_3-N, and COD. This study focused only on the last four parameters.

III. Results and Discussion

Two activated biochar loadings were used, 200 g and 400 g. From the results it can be seen that 400 g of activated biochar offered the highest removal of all the contaminants studied, this is explained by the fact that 200 g was not enough to yield high efficiency. Kitchen greywater showed the highest removal of contaminants; this shows the effectiveness of activated biochar to remove contaminants from kitchen greywater compared to other greywaters. It was observed that though activated biochar has a high removal efficiency of contaminants on kitchen greywater, this was quite low on NH_3-N (58.74%) compared to Bathroom greywater with removal efficiency of 85.71%. The high removal of NH_3-N in the bathroom greywater is explained by the low initial concentration of NH_3-N. Bathroom greywater also showed high removal efficiency of contaminants; this is mainly due to the influent having a low amount of contaminants. The lower removal was observed on laundry greywater; this explains the ineffectiveness of activated biochar to treat laundry greywater, and this might be due to the detergent that is used. Looking at the contaminants studied and considering the average removal efficiencies, TSS was the highest removed, followed by NH_3-N, then NO_3-N and the lowest being COD.

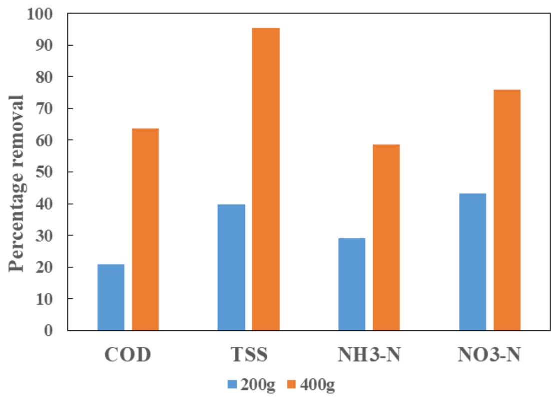

Fig. 5 Removal efficiency of kitchen greywater

Fig. 5 shows the removal efficiency of activated biochar on kitchen greywater. The highest removal was observed on TSS (85.38%) followed by NO_3-N (76%), then COD (63.64%) and lowest was on the NH_3-N (58.74). The trend of 200 g is not the same as the one for 400 g. The results obtained are closed to [26], which investigated the removal of contaminants from shower greywater. These results were also invested by another author, who found COD highly being removed [37]. The high removal COD was also observed by Boyjoo et al. [23]. The kitchen water mainly contains food waste which can easily be decomposed into the soil and give nutrients to the soil when directly applied for irrigation.

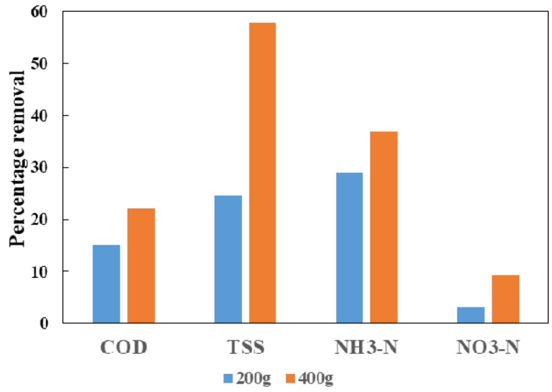

Fig. 6 Removal efficiency of laundry greywater

Fig. 6 shows the removal efficiency of activated biochar on laundry greywater. The highest removal was observed on TSS (57.84%) followed by NH_3-N (36.81%), then COD (22.13%) and the lowest was on the NO_3-N (9.3%). Pidou et al. [26] also reported the low removal of NO_3-N. The low removal efficiency of contaminants in laundry water may be due to the chemical bonds of the contaminants.

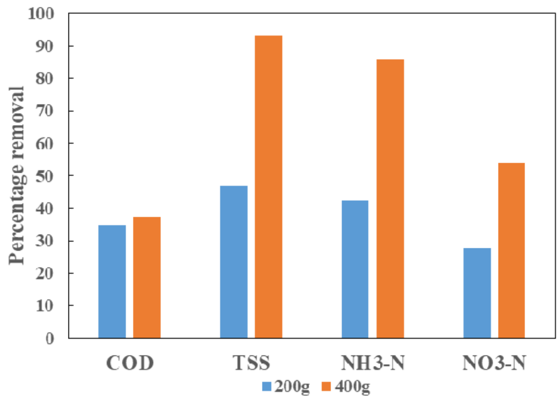

Fig. 7 Removal efficiency of bathroom greywater

Fig. 7 shows the removal efficiency of activated biochar on bathroom greywater. The highest removal was observed on TSS (93.16%) followed by NH_3-N (85.71%), then NO_3-N (53.85%) and lowest was on the COD (37.3%). The results obtained are similar to [26], which investigated the removal of shower water.

Fig. 8 shows the removal efficiency of activated biochar on floor cleaning greywater. The highest removal was observed on TSS (87.39%) followed by NO_3-N (66.67%), then NH_3-N (59.58%) and lowest was on the COD (16%). The overall removal of contaminant is high, this is explained by the low amount of contaminants, by increasing the residence time, the removal efficiency will as well be improved.

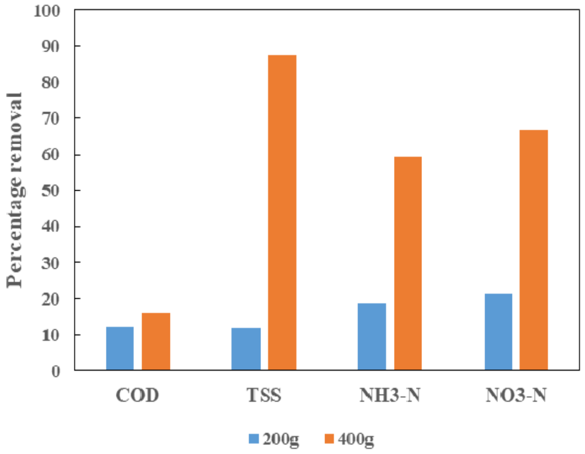

Fig. 8 Removal efficiency of floor cleaning greywater

IV. Conclusion

The experimental results indicated that activated biochar produced from agricultural waste can be relied upon as one of the cost-effective adsorbents to treat greywater for non-portable usages. The results showed that activated biochar produced from agricultural waste reduces a certain amount of pollutants from greywater. The highest reductions of pollutants were: TSS (95% on kitchen greywater), NH_4-N (85% on bathroom greywater), NO_3-N (76% on kitchen greywater) and COD (63% on kitchen greywater). Activated biochar achieved a removal efficiency of the contaminants studied at 73.44%, 67.57%, 57.41% and 31.52% on kitchen greywater, bathroom greywater, floor cleaning greywater and laundry greywater, respectively. The average calculated removal efficiency of the four greywaters was 57.49%, the removal efficiency can be improved by increasing the residence time. Activated biochar produced from agricultural waste has dual benefits when used for greywater treatment; the used adsorbent can be used for soil amendment and the effluent used for irrigation reduces fertiliser usage. The work reported in this paper has some limitation to show the full profile of the effectiveness of activated biochar produced from agricultural waste; it was therefore recommended that further studies to be done, by increasing the residence time up to 10 weeks and collecting samples weekly to monitor the removal efficiency. It is also recommended that further studies to be done looking at the higher range of contaminants, such as pH, EC, NH_4-N, NO_3-N, Tot-N, PO_4-P, Tot-P, MBAS, COD, pathogen indicators (total thermotolerant coliforms) and tracer microorganisms (enterohaemorrhagic *Escherichia coli* (EHEC).

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