

International Journal of Research Publications

Evaluation of the efficiency of constructed wetland and activated charcoal for the treatment of slaughterhouse wastewater

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Abstract

Slaughterhouses in Batticaloa district usually discharge their wastewater into the nearby soil surface and water bodies without any adequate treatment, which causes serious and deleterious threat to surrounding environment. Therefore, there is a need to treat slaughterhouse wastewater before disposal is a necessity to protect public health and environment. Even though, there are several techniques available for treating this wastewater, suitability and cost for the specific places are questionable. Therefore, this study was mainly focused to design, construct and evaluate the efficiency of constructed wetland and activated charcoal treatments for slaughterhouse wastewater on the parameters of chemical oxygen demand (COD), total dissolved solid (TDS), total suspended solid (TSS), nitrate, phosphate, biological oxygen demand (BOD) and pH. The wetland was constructed with the layers of coir fiber, gravel and sand with the dimension of 1m x 1m x 0.3m. Cattail (*Typha latifolia*) plant was used as macrophytes and activated carbon (adsorbent) was produced from coconut shell with CaCl_2 (activating agents). The results revealed that the activated carbon and constructed wetland were significantly differ in their efficacy on the treatment of slaughterhouse wastewater ($p > 0.05$). It was observed that increasing the retention time of treatment caused increase in the removal efficiency of both treatments. The maximum removal of COD, TSS, TDS, BOD₅, NO_3^- and PO_4^- with constructed wetland were 77.5%, 88.7%, 71.3%, 93.3%, 68% and 85.8%, respectively while an activated charcoal reduced COD, TSS, TDS, BOD₅, NO_3^- and PO_4^- as 74.8%, 92.5%, 79.9%, 92.6%, 47.4% and 67%, respectively. It is concluded that the constructed wetland has better performance than that of activated charcoal for the treatment of slaughterhouse wastewater with the special reference to nitrate, phosphate, BOD and COD. However, activated charcoal show better performance especially for the removal of dissolved solids.

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Key words: Constructed wetland; Activated charcoal; Slaughterhouse wastewater

1. Introduction

The ever increasing demand for water has created considerable attention towards treatment of waste water. The slaughterhouse uses large quantities of water and generates equally large quantities of biodegradable organic wastewater with medium to high strength, containing large amounts of fats, oil, grease, blood, urine, manure, hair, grit, meat tissue, suspended particles of semi-digested and undigested food within the stomach and intestine of slaughtered animal; thereby contributing to the pollutant load of water bodies (Bull et al., 1982). The major environmental problem associated with this slaughterhouse wastewater is the large amount of suspended solids and liquid waste as well as odor generation (Gauri, 2006). Effluent from slaughterhouses has also been recognized to contaminate both surface and groundwater because of abattoir processing blood, fat, manure, urine and meat tissues are lost to the wastewater streams too (Bello and Oyedemi, 2009). Leaching into groundwater is a major part of the concern, especially due to the recalcitrant nature of some contaminants (Muhirwa et al., 2010). Discharging slaughterhouse wastewater without treating them contributes to greatly degrading the aquatic environment and pollution of irrigation water (Michael et al., 1988).

Constructed wetlands are used to improve the quality of water polluted from point and non-point sources of water pollution including storm water runoff, domestic wastewater, agricultural wastewater and mine drainage. Constructed wetlands are also being used to treat petroleum refinery wastes, compost and landfill leachates, aquaculture discharges and pre-treated industrial wastewaters such as those from pulp and paper mills, textile mills and seafood processing. For some wastewaters, constructed wetlands are the sole treatment; for others, they are one component in a sequence of treatment processes (US EPA, 2008). Adsorption on activated carbon is one of the most efficient techniques used in water treatment process for the removal of organics and micro pollutants from wastes and drinking water (Abbasi and Stree, 1999). Activated carbon has been reported to have high and fast adsorption capacities due to its well developed porous structure, high surface area and high degree of surface reactivity (Chaiwattananont et al., 1998). In most of the studies, rice husk based activated carbons has removed the COD, TSS, TDS, turbidity and color from wastewater up to 90%, 80%, 70%, 99.4% and 98%, respectively while with Kikar based activated carbon are up to 88%, 80%, 65%, 98.2% and 95%, respectively (Qaisrani et al., 2016). However, technology for wastewater treatment has been developed around the world. The understanding of the advantage of sustainable and natural methods for wastewater treatment is accelerating and the last decade the research in this topic has been intensified (Kadlec and Wallace, 2009).

There are several slaughterhouses functioning at Batticaloa District and a huge amount of effluent is generated and discharged openly. It pollutes the surface water and soil as well. Therefore, slaughterhouse wastewater should be treated before discharge into water bodies to avoid environmental pollution and human health effects. Therefore, this study was focused on the use of constructed wetland and activated charcoal for slaughterhouse wastewater treatment in Batticaloa District and designed to determine the efficiency of constructed wetland and activated charcoal filter for the treatment of slaughterhouse wastewater treatment.

2. Material and methodology

2.1 Sample collection

Wastewater samples were collected from Eravur slaughterhouse in Batticaloa District and analyzed for the parameters such as COD, pH, TDS, TSS, nitrate, phosphate and BOD₅. Initially the wastewater was allowed to settle for 24 hrs as preliminary treatment and then the effluent was treated by the following methods;

a. Method – 01 (Vertical flow constructed wetland)

The wetland was constructed with dimension of 1m x1m x0.3m. Coir fiber was chopped and used for making bottom layer of 0.1m height. Medium sized gravel was added to form a middle layer of 0.1m height and fine sand was used as upper layer of 0.1m height for the construction of bed. The healthy and young cattail (*Typha latifolia*) plants were selected and transplanted into the bed. Small PVC pipe was placed at the bottom of the bed to collect the effluent.

The effluent from preliminary treatment was introduced through inlet pipe to constructed wetland. The effluent from constructed wetland was collected directly from the outlet in 3rd, 6th and 9th day and the effluent was analyzed for different water quality parameters mentioned in section 2.1 by using spectrophotometer (Genesis UV-vis), pH meter (EUTEC Ph-700) and multi-meter (Combo by HANNA).

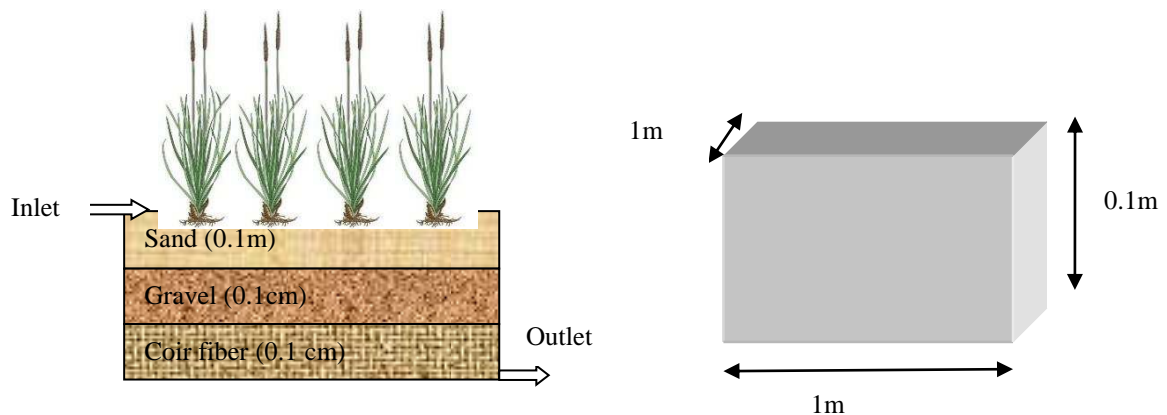


Fig. 1. Schematic diagram of constructed wetland

b. Method – 02 (Activated charcoal filter)

The required amount of coconut shell was burnt in a burning sink and allowed to cool completely. The burnt coconut shell was soaked in 25% of calcium chloride solution for a day. Then, it was rinsed thoroughly and allowed the water to drain out. Subsequently it was dried for three hours at 215⁰F in muffle furnace and ground to fine particles. A five litre plastic bottle was used as filter container and it was filled with activated charcoal for about 0.3m height. Small PVC pipe was fixed at the bottom of the bottle to collect the effluent.

The effluent from preliminary treatment was poured into activated charcoal. The effluent from activated charcoal filter was collected directly from the outlet in 3rd, 6th and 9th day and the effluent was analyzed for

different water quality parameters mentioned in section 2.1 by using spectrophotometer (Genesis UV-vis), pH meter (EUTEC pH-700) and multi-meter (Combo by HANNA).

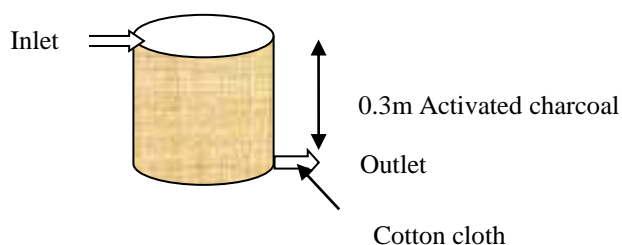


Fig. 2. Schematic diagram of Activated charcoal filter

2.2 Experimental Setup and Procedure

The experiment was laid out in a complete randomized design (CRD). The experiment consists two treatments as activated charcoal and constructed wetland with three replicates. The data were statistically analyzed through SAS software (SAS version 9.1). Treatment means were compared using t-test at 5% significant level.

3. Results and discussion

Table 1. Changes of water quality parameters with retention time

Parameters	Initial	3 rd Day		6 th Day		9 th Day	
		CW	AC	CW	AC	CW	AC
PO ₄ ³⁻ (mg/l)	16.8±1.6	12.0±1.3	13.5±0.7	5.5±1.8	7.5±0.6	2.4±0.6	5.6±0.7
BOD ₅ (mg/l)	551.7±12.6	345.0±10.0	383.0±17.5	117.3±9.0	153.3±10.4	30.3±5.5	41.0±3.6
COD ₅ (mg/l)	1193.3±34.5	918.3±0.3	977.0±24.0	558.3±16.0	631.0±17.7	253.3±10.4	311.3±21.4
Nitrate (mg/l)	32.3±2.5	25.3±1.5	27.0±2.0	17.3±1.5	22.17±1.26	10.3±1.5	17.0±1.0
pH	8.7±0.1	7.7±0.1	7.8±0.2	7.3±0.1	7.31±0.0	7.2±0.0	7.2±0.0
TDS (mg/l)	296.7±25.2	213.3±20.0	164.0±11.5	153.3±12.6	100.3±22.8	85.0±5.0	59.7±13.6
TSS (mg/l)	649.3±6.0	354.3±9.5	300.0±10.0	90.0±5.0	75.0±5.0	73.3±2.9	49.0±3.6

CW- Constructed wetland, AC- Activated charcoal.

Values are means ± standard deviation of replicate determination.

According to the t-test at 5% significant level (p<0.05), p value=0.05

3.1 Phosphate

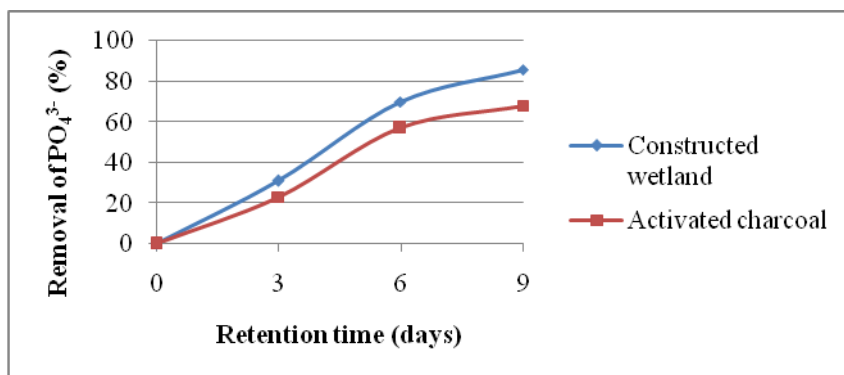


Fig. 3. Removal of phosphate with retention time

Figure 3 illustrates the phosphate removal efficiency of the treatments constructed wetland and activated carbon with retention time. It was found that the phosphate removal was increased with retention time. It could be the reason that the phosphate is removed from the water either by adsorption to the metals ions or taken up by plants or fixed in the clay minerals. Similar results were found by Sundaravadivel, (2001) who reported that the decomposition of litter (dead plants), organic matter in the wetland and wetland plant also takes up phosphorus, thereby reducing levels in the wetland and Siong et al., (2013) also reported the pores of activated carbon trapped and locked nutrient like phosphorous in wastewater due to its excellent adsorption capacity. The removal efficiency of phosphate is higher in constructed wetland where macrophytes present in wetland doing major roll in phosphate removal. It is proved by Picard et al., (2005) the plant present in wetland help in phosphate cycling and microbial processes, which are major processes involved in nutrient removal. The removal efficiency of phosphate in constructed wetland and activated charcoal were achieved 85.8% and 67%, respectively.

3.2 Biological oxygen demand (BOD)

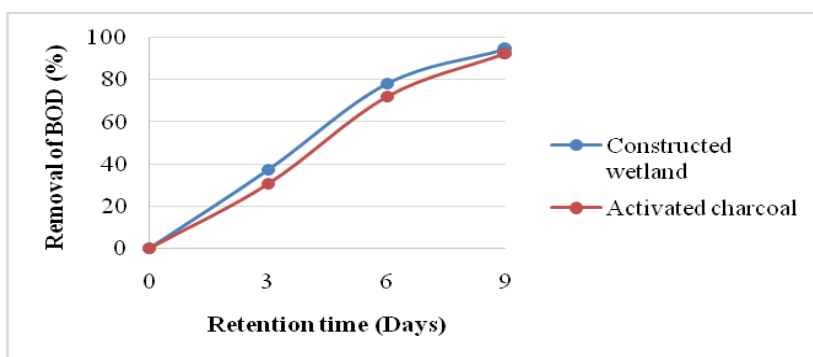


Fig. 4. Removal of BOD₅ with retention time

Initial BOD₅ of 551.7±12.6 mg/l (Table 1) was reduced gradually with time to the values of 30.3±5.5 mg/l and 41.0±3.6 mg/l in constructed wetland and activated charcoal respectively. In both treatments major removal mechanisms of BOD₅ are volatilization, photochemical oxidation, sedimentation, sorption and microbial degradation by fermentation, aerobic and anaerobic respiration. In addition, bioaugmentation of the sediment and sorption by macrophytes is particular importance (Duarte-Davidson and Jones, 1996). It was found that the removal efficiency was increased with increasing time in both treatments. Akratos et al., (2008) and Sindilariu et al., (2009) reported that greater retention time of water in constructed wetlands was the most important positive factor in BOD removal efficiency.

Biological carbon mineralization is a significant mechanism of BOD removal in charcoal. This has been demonstrated by Trois and Polster, (2007). They reported that the high observed potential respiratory activity of the biofilms and the organic carbon charcoal can provide substrate for microbial communities, thus increasing their enzymatic capacity to degrade wastewater. According to the results of this study 91.96% of BOD removal was achieved at 9th day by activated charcoal treatment. The constructed wetland has achieved 93.29% of BOD removal at 9th day. In constructed wetlands BOD₅ is removed by the processes of biological degradation and sedimentation. The abatement process of BOD₅ is mainly carried out by bacterial activity (aerobic and anaerobic) with greenhouse gases production and emission to the atmosphere (Mander, 2014 and Barbera, 2015) and by the sedimentation and filtration of particulate organic matter (Vymazal, and Kropfelova, 2009).

3.3 Chemical oxygen demand (COD)

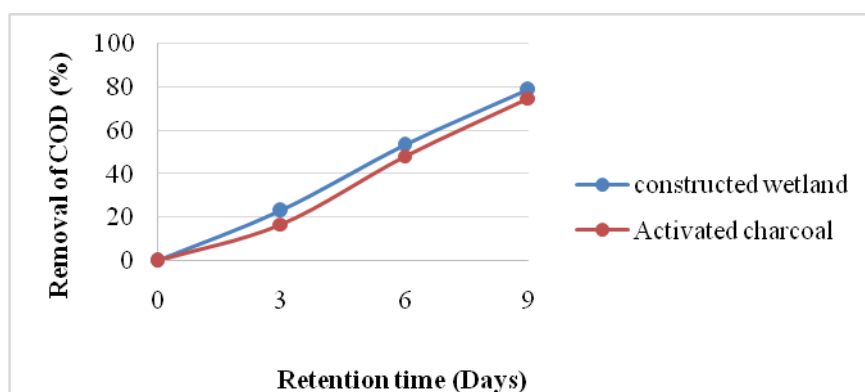


Fig. 5. Removal of COD with retention time

Figure 5 describes the reduction of COD with retention time. It could be either by adsorption of organic matter to the porous structure of activated carbon or aerobic degradation of the organic load of the wastewater by the microorganism. The COD removal efficiency was increased along with the retention time in constructed wetland and activated carbon. This may be due to the fact that during the long contact time between biomass (constructed wetland) or substrate (activated carbon) and pollutants. Therefore, biodegradation rate would be increased and the removal capacity of COD from wastewater ultimately increased. As the efficiency was very high from the beginning on, the first process leading to the reduction of organic matter was probably adsorption. Over time a biofilm formed and biological activity contributed more and more to the organic matter removal (Lens et al., 1993, Dalahmeh et al., 2012). Higher COD sorption rates

at the beginning of the treatment may be due to the large number of surface adsorption sites available to capture pollutants from the solution (Mall et al., 2006) and then it decreased slightly with time because of the continuous removal of COD by biodegradation might be a stress for their metabolism of organisms which are present in wetland and the activated carbon reached its maximum adsorption capacity. Higher removal efficiency of COD was found in constructed wetland compared to activated carbon. It could be the reason that the wetland was able to oxygenate the beds to a level that supports the aerobic degradation of the organic load of wastewater. In addition the vegetation provides a substrate (roots, stems, and leaves) upon which microorganisms can grow as they break down organic molecules (EPA, 1988). The removal efficiency of COD in constructed wetland and activated charcoal was achieved 77.5% and 74.8%, respectively.

3.4 Nitrate

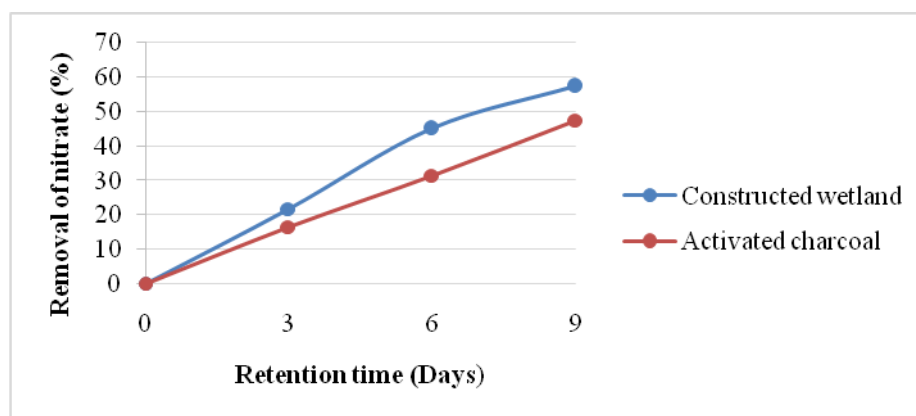


Fig. 6. Removal of nitrate with retention time

According to the result, removal efficiency of Nitrate was increased with retention time in both treatments. Bastviken (2006) and Fink and Mitsch (2004) found that long retention time and accumulation of the organic material increase the rate of denitrification in wetland. This ultimately reduced the amount of nitrate from wastewater. Hasani and Naserkhaki (2016) also documented that increased contact time has a positive effect on the efficiency of nitrate removal by activated charcoal. Shahmoradi et al., (2015) demonstrated that activated charcoal obtained from rice husk and sludge of paper industry wastewater treatment has high efficiency in adsorbing nitrate. According to the graph (Figure 6) higher removal efficiency of nitrate was observed in initial period because of increased uptake of nitrogen by wetland plants and microflora and by denitrification process. However, nitrogen removal efficiency was dropped slightly after sixth day due to increased dissolved oxygen (DO) by passive aeration and photosynthesis of wetland plant which enhanced nitrification rates. These results are in accordance with Vymazal (2015) who found that constructed wetland offered good requirements of oxygen which leads unfavourable conditions for the denitrification of NO_3^- . Faulwetter et al. (2009) also stated high DO in wetlands causes the nitrification process through a decrease in ammonia levels and an increase of nitrates. The removal efficiency was increased with retention time in constructed wetland was also due to an increase in thickness of biological membrane formed around the sediment which led to the direct emergence of an oxygen deficient area around the bed particles that helped to remove nitrates, accumulation of organic matter within the bed and higher retention time.

Andersson et al. (2005) has also proven that the removal efficiencies of nitrate in wetland depend on hydraulic retention time of the wetlands, oxygen concentration and organic matter content.

In activated charcoal, the removal efficiency was increased gradually with time and finally reached the optimum value of 47.4% at 9th day due to the saturation of the adsorbent surface of nitrate and adsorption rate reaches equilibrium. Comparable results were stated by Yuh-Shan Ho (2005) that high velocity of adsorption level is due to the capacities available for adsorption on adsorbents in early days. Filling these capacities, the rate of adsorption is reduced. The removal efficiency of nitrate in constructed wetland and activated charcoal was achieved 68% and 47.4%, respectively.

3.5 pH

The Table 1 shows different pH values in constructed wetland and activated charcoal with retention time. Thus, pH of effluent tended towards almost neutral values. This convergence of pH values suggests that this wetland sediment and activated carbon may have ability to reduce the pH which may be due to the presence of acidic components in its composition such as weak acids (e.g. Carbonic acid).

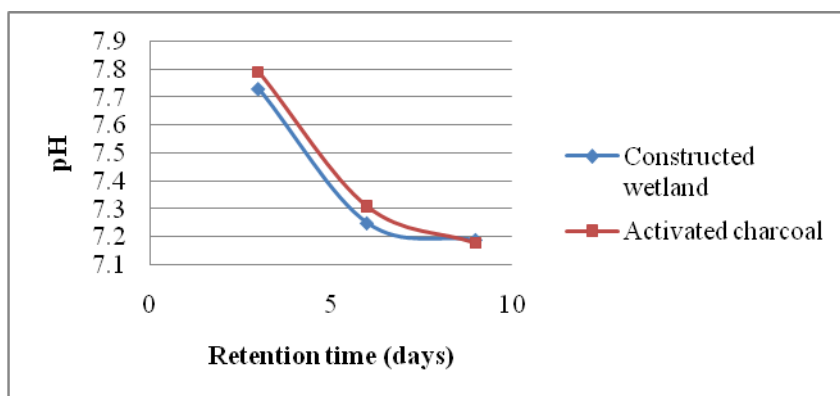


Fig.7. Changes of pH with retention time

The changes of pH with retention time are illustrated in figure 7. pH was reduced gradually in both treatments. Dordio et al., (2007, 2009) stated that wetland sediments and activated carbon contains many amphoteric constituents that could influence in pH of the wastewater. It was observed that the pH plummeted in first six days values closer to 7.28 and at ninth day, the pH of both treatments was almost neutral. Richard (1996) found that an effective remediation of the pH is accomplished by activated carbon surface. Mayes et al., (2009) also reported that the aquatic macrophytes in wetlands mainly provided a substratum. Hence, that decomposing microorganisms raised free carbon dioxide rate in the column water. The CO₂ from the respiration of microorganisms in the constructed wetland might have helped in the decrease of pH at the outlet.

3.6 Total dissolved solids (TDS)

The amount of dissolved solids was considerably decreased along with the time in the treatments of constructed wetland and activated charcoal. This result clearly indicates that constructed wetland and activated carbon treatments are efficient technologies in the treatment of wastewater especially in removing the dissolved solids.

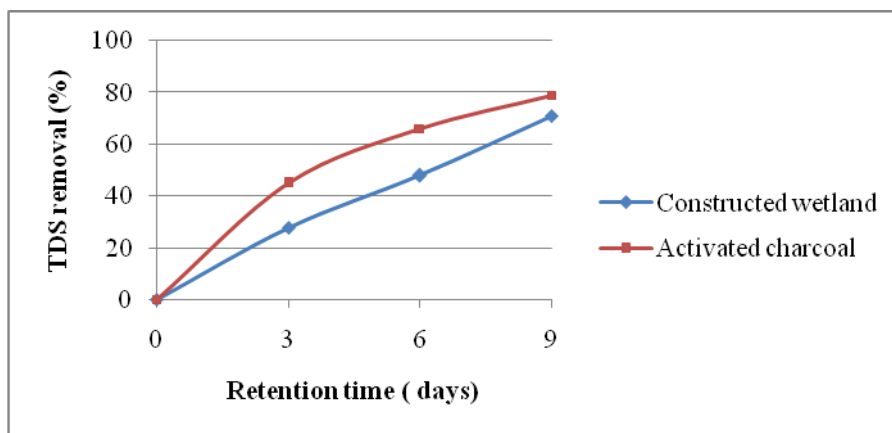


Fig.8. Removal of TDS with retention time

In constructed wetland there are three main processes that remove TDS namely binding to soils, sedimentation and particulate matter, precipitation as insoluble salts and uptake by bacteria, algae and plants (Kadlec and Knight, 1996). A certain level of ions in water is really necessary for plant and they are biologically utilized or chemically reactive in wetland. Therefore, it may be the reason for the rapid reduction of TDS from wastewater. Besides, TDS often contain certain concentration of unreactive dissolved compounds which cannot be removed by wetland. This could be the reason that the removal of TDS from wastewater slows down with time. In activated charcoal treatment, removal of TDS could be achieved by ion-exchange (H-exchange, OH-exchange), chelation with metallic cations and the formation of various bonds (hydrogen and anion-cation) as well as by the precipitation of Al, Ca, and Fe compounds. These mechanisms have been confirmed by experimental studies by Dufort and Ruel (1972).

3.7 Total suspended solids (TDS)

According to the present study results, both treatments have removed considerable amounts of suspended solids from wastewater. It could be the reason of sedimentation, filtration, adsorption onto biofilm and flocculation/precipitation. Further, the surface area of the plant stems also traps fine materials within its rough structure. According to Vymazal et al., (1998) reported that the suspended solids are mainly removed in constructed wetland by physical processes such as sedimentation and filtration. Filtration occurs by the impaction of particles onto the roots and stems of the macrophytes or onto the soil/gravel particles in sediments. Activated carbons generally remove TSS by physical sorption, filtration and precipitation (Gravelle and Landreville, 1980, Healy et al., 2007 and Rodgers et al., 2004).

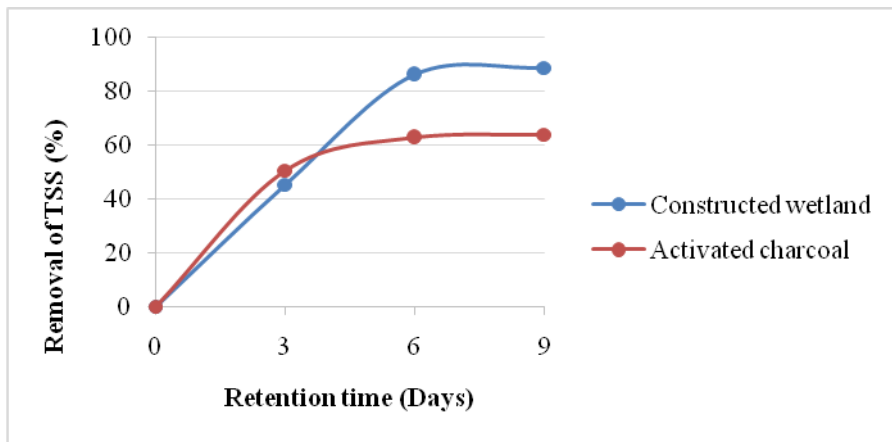


Fig.8. Removal of TSS with retention time

The removal of TSS with time in both treatments can be graphically represented in figure 9. According to the graph it is clear that the amount of suspended solids decreased with increasing the time of treatment. This higher removal of suspended solids indicated the effectiveness of activated carbon and constructed wetland. Chaiwattananont et al., (1998) reported that activated carbon has high and fast adsorption capacities due to its well-developed porous structure, high surface area and high degree of surface reactivity. Therefore, this may be the reason for the rapid removal of TSS observed in activated charcoal. Nisha et al., (2016) demonstrated activated carbon prepared from coconut shell found to highly effective in the reduction of TSS in wastewater. They also reported that the high surface area of activated carbon is responsible for the effective reduction of TSS and increase in surface area is also responsible for the increase number of sites for adsorption. The higher removal of TSS was observed from beginning on in activated charcoal. These finding is in line with the findings of Mall (2006) who proposed that higher TSS sorption rate was observed at beginning of the treatment may be due to the large number of surface adsorption sites available to capture pollutants from the solution. In addition, Viraraghavan and Kikkeri (1988) reported that activated carbon removed 94% suspended solids from slaughterhouse wastewater during first 5 days period.

4. Conclusion

The results of the study revealed that both constructed wetland and activated carbon have an ability to treat slaughterhouse wastewater. These both treatments exhibited quite reasonable functionality for removal of pollutants from slaughterhouse wastewater. The initial mean values of slaughterhouse wastewater for Nitrate, phosphate, BOD5, COD, TSS and pH were higher compared to Central Environment Authority (CEA) permissible limits for safe discharge of industrial wastewater into inland water bodies. Therefore, this study showed that there was significant reduction in these parameters with the treatments of constructed wetland and activated charcoal. The constructed wetland was found to more efficient than activated charcoal for the removal of COD, phosphate, BOD5 and nitrate but higher removal efficiency of TDS was observed in activated charcoal. However, the TSS removal efficiency for both treatments was same. The nitrate, phosphate, COD and BOD5 of effluent treated with activated charcoal had slightly higher than that of

maximum permissible limit of CEA standards for the safe discharge of industrial wastewater into inland water bodies. But it was lower than the Central Environment Authority (CEA) maximum permissible limits for industrial waste discharged on land for irrigation purpose. Finally, it could be concluded that the constructed wetland ensure a more stable removal of pollutants from slaughterhouse wastewaters in comparison with activated charcoal but activated charcoal has shown a better performance especially for the removal of dissolved solids.

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