Research Journal of Applied Sciences, Engineering and Technology 11(10): 1066-1070, 2015
DOI: 10.19026/rjaset.11.2120
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: June 8, 2015 Accepted: July 8, 2015 Published: December 05, 2015

Research Article

An Integrated Attached Growth Bioreactor for the Treatment of Wastewater

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Abstract: An integrated attached growth bioreactor was evaluated in this study for the removal of organic matter (COD). The bioreactor integrated the aerobic tank, anoxic tank and the secondary clarifier in a single unit. An attached growth media was submerged into the aerobic tank to improve the growth of biomass while bio-balls were submerged into the anoxic tank. Synthetic wastewater simulating medium and high strength domestic wastewater were pumped into the reactor for biodegradation. Hydraulic Retention Time (HRT) was varied in the range 12 and 7.2 days. Influent COD was introduced in two phases. Phase 1 consists of COD 400 mg/L whereas phase 2 consists of COD 650 mg/L. In phase 1, steady state was attained from day 18 until day 26. Effluent concentrations of COD were approximately 9 mg/L at HRT of 12 days. The effluent COD concentration increased (16 mg/L) when COD concentration was increased to 650 mg/L at HRT of 12 days. Effluent COD decreased from 19-9 mg/L when HRT was increased from 7.2-12 days. The effluent COD obtained in this study was below the Malaysia Department of Environment (DOE) guideline limit Standard A (120 mg/L). Residual ammonia, nitrate and total suspended solids were also monitored at steady state. Results show a 97, 87 and 97%, respectively removals for ammonia, nitrate and TSS, respectively. The attached growth media in the aerobic and anoxic tanks provided a large surface area for the attachment of biomass. The bioreactor performance shows it can serve as an alternative footprint for the treatment of wastewater.

Keywords: Attached growth, bioballs, COD, HRT, integrated bioreactor, MLSS, perspex

INTRODUCTION

The constant deterioration of water bodies can be largely attributed to anthropogenic and natural activities. Anthropogenic activities could arise from industrial sources such as urban and agricultural run-offs, industrial and sewage run-offs whereas natural activities could include floods and earthquake. Anthropogenic activities constitute a large percentage of water body contamination due to the presence of nitrogenous compounds (ammonia, nitrate and nitrite) (Ezechi *et al*., 2014a). The composition of pollutants in water bodies vary because wastewater is discharged from different industrial sources. For instance, the composition of produced water varies from other wastewaters due to its long term interaction with underground formations (Ezechi *et al*., 2012, 2014b; Isa *et al*., 2014). Therefore suitable, efficient and accessible techniques are required to mitigate the deterioration of water bodies through effective treatment of wastewater from anthropogenic sources especially with the advent of emerging pollutants.

Several methods such as Fenton oxidation process (Meriç *et al*., 2004), coagulation and flocculation (Guida *et al*., 2007), reverse osmosis (Chianese *et al*., 1999), electrochemical processes (Panizza and Cerisola, 2008), adsorption process (Bansode *et al*., 2004), biological process (LaPara *et al*., 2001) have all been employed in the removal of COD from various wastewaters. Biological treatment processes have been most effective for the removal of COD due to biodegradation of organic matter by consortium of bacteria. However, some significant demerits exist such as use of large space for installation, odorous smell and production of high volume of sludge. Sludge disposal in landfills, land application or incineration constitute about 60% of total cost of conventional biological treatment process (Wei *et al*., 2003). In Malaysia, the Department of Environment (DOE) recently revised the effluent discharge limits guideline for sewage treatment plants due to high contamination of water bodies (Malaysia, 2009). With rapid increase in population growth, urbanization and industrialization, many landfills sites are filled and developing new landfills are difficult due to its environmental consequences (Ezechi *et al*., 2011). Hence, it is imperative to develop alternative biological treatment process that meets regulatory goals.

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Integrated wastewater treatment is considered a potential alternative to conventional wastewater treatment system. Recently, few studies successfully utilized anaerobic-aerobic integrated bioreactors for the treatment of Palm Oil Mill Effluent (POME) (Chan *et al*., 2012a, b). Integrated bioreactors combines individual reactor degradation pathways into a single pathway and enhance the overall performance of the system (Chan *et al*., 2009). Integrated bioreactors are reportedly cost effective, efficient and smaller footprint (Chan *et al*., 2009). In nuclear settlements and urban cities with compact town planning, integrated bioreactors can effectively fit into the least space and qualitatively degrade organic matter.

Consequently, the performance of integrated bioreactors can further be enhanced by the inclusion of filter materials. The advantages of such materials include prevention of washout by retaining higher biomass concentration within the bioreactor, high metabolic and degradation activity within the bioreactor compartment, high resistance to toxicity and other adverse effects and reduction of sludge settling periods (Chang *et al*., 2010). Suitable and appropriate filter material are chemically stable, resist attrition, possess high surface area, easy to install and prevent clogging.

In this study, an aerobic-anoxic integrated bioreactor equipped with filter material made of perspex and bio-balls were examined for the treatment of wastewater simulating medium and high strength domestic wastewater. Bioreactor performance was evaluated from the degradation of organic matter (COD).

METHODOLOGY

Bioreactor configuration: The bioreactor configuration is post anoxic. The aerobic tank consist of a baffle and openings at the edge of the bottom for easy flow of sample into the attached coupled aerobic tank. The baffle system allow movement of the sample in upflow pattern into the anoxic tank. The volume of aerobic tank is 10 L and equipped with a filter attached growth media made from perspex having 10 layers with significant pore openings for the flow of wastewater and air. The volume of anoxic tank is 20 L with an opening towards the bottom to enable free flow of sample and solids to the clarifier. The anoxic tank is equipped with bio-balls held together with tiny fish net as filter attached growth media for the growth of biomass. The volume of secondary clarifier is 150 L. Mixed liquor volatile suspended solids were monitored by scrapping one layers/bio-ball of the filter materials at steady state and assume surface coverage of biomass on all layers.

Wastewater preparation: The wastewater was a synthetic preparation simulating medium and high strength domestic wastewater (400 and 650 mg/L, respectively). pH of the bioreactor was maintained by the addition of $NaHCO_3$.

Bioreactor operation: The influent sample was pumped into the aerobic tank using a Masterflex peristaltic pump at HRT of 7.2 and 12 days. The aerobic tank is integrated into the anoxic tank and the anoxic tank integrated into the clarifier. The Mixed Liqour Recirculation (MLR) was conducted for 1 min at 90 min interval into the anoxic tank to provide agitation. The bioreactor Solid Retention Time (SRT) was set at 30 days. Biomass from a sewage treatment plant was used as seed for bioreactor start-up. The Mixed Liquor Suspended Solids (MLSS) concentration in the reactor was 3000 mg/L. Oxygen was supplied to the aerobic tank by means of air pumps. The biomass acclimation period was 20 days. Samples were collected for analysis from the influent tank, aerobic tank, anoxic tank and effluent at regular intervals of 2 days. The designed daily mixed liquor temperature of the bioreactor was $25^{o}C \pm 2$.

Analytical methods: Chemical Oxygen Demand (COD) was analyzed by the closed reflux method (Walters, 1989). Total Suspended Solids (TSS), Mixed Liquor Suspended Solids (MLSS) and Mixed Liquor Volatile Suspended Solids (MLVSS) were analyzed according to the 21^{st} edition of standard methods for the examination of water and wastewater (Eaton *et al*., 2005). Ammonia and Nitrate was analysed by Nessler and cadmium reduction method respectively.

RESULTS AND DISCUSSION

Organic matter removal (COD): Figure 1 shows the Chemical Oxygen Demand (COD) degradation. An average influent COD concentration of about 400 mg/L was applied to the bioreactor during the first stage. After 20 days of acclimation, sample were collected from all compartments of the bioreactor and analysed for residual COD concentration. In the first influent COD concentration of 400 mg/L (HRT 12 days), organic matter degradation began from day 2 to day 18 for both aerobic and anoxic tanks.

Similarly, the net effluent COD also decreased from day 2 to day 18. From day 20 to day 26, all bioreactor compartments attained steady state and net effluent concentration (9 mg/L) was significantly below the DOE Malaysia Standard A guideline of 120 mg/L. On day 27, the second phase of the experiment was initiated with an average COD concentration of about 650 mg/L. A significant tilt increase was observed in effluent concentrations of the aerobic tank, anoxic tank and net effluent due to shock effect and acclimation of biomass to new organic loading. From day 28 to day 42, effluent COD concentrations of the aerobic tank,

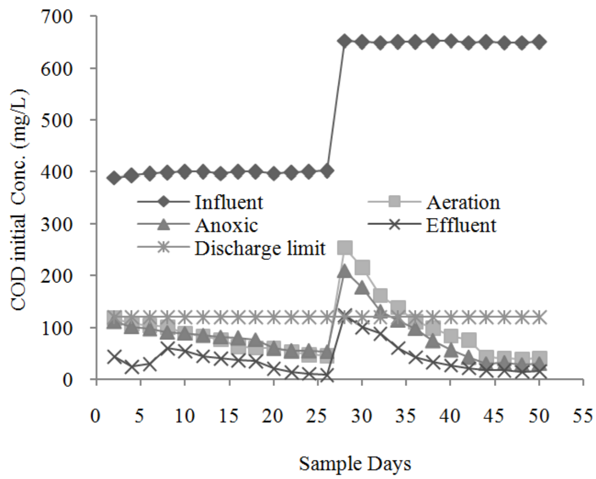

Fig. 1: COD removal in phases 1 and 2

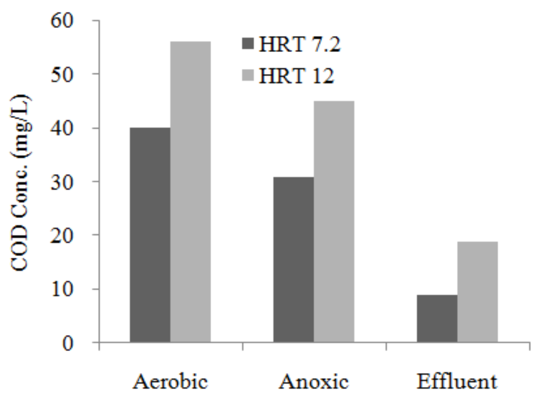

Fig. 2: Effect of HRT

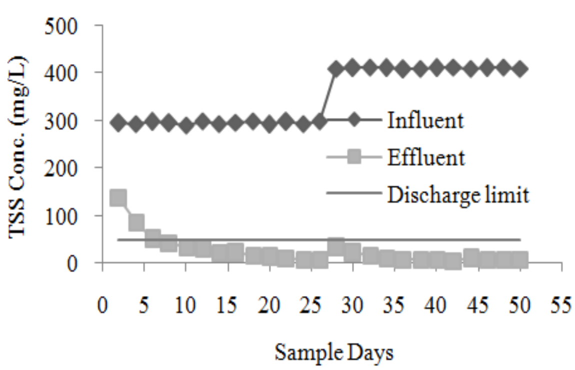

Fig. 3: TSS removal

anoxic tank and net effluent gradually decreased and attained steady state from day 44 to day 50. The net effluent concentration of COD at steady state in phase 2 was 16 mg/L. The rapid degradation of organic matter by the bioreactor could be attributed to aggregation of biomass consortium within the attached growth media. The net effluent concentration of COD for the second organic loading was below the DOE Malaysia Standard A guideline of 120 mg/L. Significantly, the major activities in the bioreactor in phase 1 could be carbonaceous substrate removal and endogenous respiration whilst in phase 2, stabilization of biomass and exogenous substrate consumption was predominant (Hamoda *et al*., 1996). COD removal was markedly higher in the aerobic tank than in the anoxic tank. This could be due to concentration gradient between the two compartments. The aerobic tank receives the sample first before it flows into the anoxic tank. Similar observation was reported by Hamoda *et al*. (1996) in their study of biological nitrification kinetics in a fixed-film reactor. They observed that biodegradation of organic matter was more eminent in the first compartment more than the second, third and fourth compartments.

Effect of HRT: Hydraulic Retention Time (HRT) was varied in the range 7.2 and 12 days for COD concentration of 400 mg/L (Fig. 2). Influence of HRT was observed in all bioreactor compartments when HRT was increased from 7.2 to 12 days. As the HRT is increased, COD removal increased in all compartments. The COD concentration in the aerobic compartment for HRT 7.2 and 12 days were 56 and 40 mg/L; 45 and 31 mg/L for anoxic compartment; 19 and 9 mg/L for effluent compartment. This observation is in agreement with reports elsewhere (Mann and Stephenson, 1997).

MLVSS and TSS: The growth of biomass was monitored in both aerobic and anoxic tanks at steady states. It was observed that the growth of biomass in the anoxic tank was markedly inferior to the aerobic tank. This can be attributed to substrate utilization by biomass in the various compartments. Similar observation has been reported elsewhere (Ramos *et al*., 2007). Total Suspended Solids (TSS) were monitored to examine solid removal from the net effluent. The results obtained (Fig. 3) shows effective biodegradation of solids in both the aerobic and anoxic tank. In phase 1, a net effluent TSS concentration of 8.5 mg/L was obtained from an initial TSS concentration of 300 mg/L. The net effluent TSS concentration remained constant (9 mg/L) in phase 2 from initial TSS concentration of 410 mg/L. Thus, effective biodegradation of TSS in both the aerobic and anoxic tank resulted to low TSS concentration in the effluent sample. Effluent TSS concentration in both phase 1 and 2 were below the DOE Malaysia guideline Standard A of 50 mg/L.

Ammonia was monitored in the effluent concentration and was found to be constant at the first and second steady state. An ammonia removal of about 97% was achieved from initial concentration of 40 and 55 mg/L, respectively. A small decrease in nitrate removal was observed (from 89-87%) when organic loading was increased. Nitrate was produced in the aerobic tank by oxidation of ammonia by nitrifying bacteria and was used up by denitrifying bacteria in the anoxic tank through mass transfer from the aerobic tank. MLVSS was monitored at each steady state by scraping the layers and assume uniform surface coverage of biomass on all layers. It was observed that biomass concentration increased with increase in organic matter.

CONCLUSION

The efficiency of Integrated attached growth bioreactor was evaluated in this study for the treatment of wastewater simulating medium and high strength domestic wastewater across two influent concentrations. The reactor was effective and results show that COD and TSS was reduced below the DOE Malaysia Standard A guideline for sewage effluent. Ammonia and nitrate were also removed significantly. The bioreactor efficiency was enhanced by the attached growth media, which enabled the aggregation of biomass consortium and improved process efficiency. This study has shown that integrated attached growth bioreactor can potentially treat wastewater below stringent limits.

ACKNOWLEDGMENT

This study was sponsored by Universiti Teknologi PETRONAS (UTP) through the Graduate Assistantship Scheme (GA) and Idea Generation Fund (i-GEN) grant number 015210-004. The authors are therefore grateful to Universiti Teknologi PETRONAS (UTP) for supporting this study.

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