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Chemical Oxygen Demand Removal from Wastewater by Integrated Bioreactor

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ABSTRACT

An integrated Bioreactor (IB) with three compartments (Aerobic, Anoxic and Clarifier) of total volume 180 L was successfully employed for the removal of Chemical Oxygen Demand (COD) from a simulated synthetic domestic wastewater at 25±2°C. Chemical Oxygen Demand (COD) (250-500 mg L^{-1}) and hydraulic retention time (HRT 12 and 7.2 days) were varied. The bioreactor was inoculated with MLSS concentration of 3000 mg L^{-1}. Results show that with initial COD concentration of 500 mg L^{-1}, COD concentration decreased to 92-80 mg L^{-1} in the aerobic compartment and 81-71 mg L^{-1} in the anoxic compartment when HRT was raised from 7.2-12 days. COD concentration in the effluent was 74 and 44 mg L^{-1} at HRT of 7.2 and 12 days, respectively. Increased in organic loading did not show any significant effect in the aerobic compartment (83.4 and 84%) at 250 and 500 mg L^{-1} COD concentration, respectively. However, COD removal decreased in the anoxic compartment (90 and 86%) and the net effluent (95 and 91%) at 250 and 500 mg L^{-1} initial COD concentration. The substrate utilization rate was higher for the aerobic compartment (1.1919 day^{-1} m^3 kg^{-1}) but lower for the anoxic compartment (0.1725 day^{-1} m^3 kg^{-1}). Growth of microbial population was most significant in the aerobic compartment. Ammonia and nitrate was monitored and a removal of 94 and 83% was achieved respectively, at steady state. The obtained results demonstrate that an IB can be applied in the removal of medium strength COD from wastewater.

Key words: COD, integrated bioreactor, MLVSS, HRT, wastewater, ammonia

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 carbonaceous compounds (Ezechi *et al*., 2014a). Wastewater composition varies depending on its source. 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). Generally, organic composition (COD) is a significant wastewater pollutant, which has been a subject of interest for researchers. Chemical Oxygen Demand (COD) is a measure of the oxygen equivalent of organic materials in wastewater and a widely used indicator of wastewater quality (Kang *et al*., 1999; Metcalf and Eddy, 2004). Many countries have stringent regulations on the discharge of wastewater with high concentration of COD. For instance, the Malaysia Department of Environment (DOE) recently revised the COD discharge limit for sewage effluents Standard "A" to 120 mg L^{-1} in order to reduce water body deterioration (DOE., 2009).

Several methods such as Fenton oxidation process (Meric *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.

Conventional biological wastewater treatment is a proven method for the removal of nutrient and other wastewater pollutants. It has been widely and successfully used in various configurations depending on the objective of such process. 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). With rapid increase in population growth, urbanization and industrialization, many landfill sites are filled and developing new landfills are difficult due to its environmental consequences (Ezechi *et al*., 2011, 2015). Hence, it is imperative to develop alternative biological treatment processes that meets the objectives of regulatory bodies.

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 are reportedly cost effective, efficient and smaller footprint which combines individual bioreactor degradation pathways into a single pathway and enhance the overall performance of the system (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.

The objective of this study is to evaluate the performance of an Integrated Bioreactor (IB) for the removal of Chemical Oxygen Demand (COD) from wastewater. The effect of organic matter concentration and hydraulic retention time on all the bioreactor chambers were examined.

METHODOLOGY

Bioreactor configuration: The bioreactor has a total volume of 180 L consisting of aerobic compartment (10 L), anoxic compartment (20 L) and secondary clarifier (150 L). The bioreactor has a post-anoxic design with the aerobic compartment integrated into the anoxic compartment and both compartments integrated into the secondary clarifier. The influent wastewater flows into the aerobic zone in a downflow process for biodegradation. The sample then flows into the baffled compartment through a series of holes at the bottom of aerobic compartment and forced into the anoxic compartment in an upflow process. The sample then flows into the secondary clarifer through the bottom hole of the anoxic compartment. Mixed Liquor Recirculation (MLR) into the anoxic compartment is automatically conducted for one minute (16 times day^{-1}).

Wastewater preparation: The wastewater was a synthetic preparation (Purina Alpo) simulating two COD organic loadings of low and medium strength domestic wastewater. Ammonia was introduced into the wastewater by the addition of appropriate quantity of ammonia chloride. Wastewater was prepared freshly on daily basis according to the experimental flowrate.

Bioreactor operation: Seed biomass were collected from a domestic sewage treatment plant with a mixed liquor suspended solid concentration of 3000 mg L^{-1}. The influent sample was pumped into the aerobic compartment using a Masterflex peristaltic pump at two different Hydraulic Retention Time (HRT) of 7.2 and 12 days. COD influent concentration of 250 and 500 mg L^{-1} were applied to the bioreactor respectively. Wastewater flows from the baffled zone of the aerobic compartment into the anoxic compartment and finally into the secondary clarifier. The Mixed Liqour Recirculation (MLR) was conducted into the anoxic compartment to provide agitation and mixing. The reactor Solid Retention Time (SRT) was set at 30 days. Oxygen was supplied to the aerobic compartment by means of air pumps. Biomass was introduced into the bioreactor compartments and was allowed an acclimation period of 20 days at a daily mixed liquor temperature of 25±2°C. Bioreactor performance was evaluated every two days with samples collected from the influent tank, aerobic compartment, anoxic compartment and effluent zone. The bioreactor was considered in steady state when all its compartments achieve a constant COD removal rate (+5) over a period of 8-10 days. pH, DO and temperature were daily monitored concurrently using a pH meter (Sension^{TM}), DO meter (YSI 550 A) and a thermometer (Thermolyne P/N MEX-147 IMM 76 MM MCT). COD concentration was measured using spectrophotometric method. All analysis were triplicated.

RESULTS AND DISCUSSION

Effect of organic matter: Effect of organic matter was investigated by varying COD concentration in the range 250-500 mg L^{-1} (Fig. 1). Biodegradation of organic matter was more significant in the aerobic compartment during stage 1 at HRT of 12 days. COD concentration decreased from 250-40 mg L^{-1} in the aerobic compartment at steady state. The COD concentration in the anoxic compartment at steady state in stage 1 was 23 mg L^{-1} whilst the effluent COD concentration was 11 mg L^{-1} at steady state. Raising the organic loading from 250-500 mg L^{-1} caused a slight increase in the effluent of all compartments but stabilized within 5 days. The biodegradability in stage 2 was similar to stage 1 with significant percentage of COD removed from the aerobic compartment prior to the anoxic compartment. The bulk of the organic matter biodegradation was observed in the aerobic compartment. The COD concentration in the aerobic, anoxic and net effluent compartments in stage 2 at steady states were 80, 71 and 42 mg L^{-1}, respectively. The carbon source for the anoxic compartment was provided by mass transfer of residual carbon from the aerobic compartment. As a result, the activity of the anoxic compartment

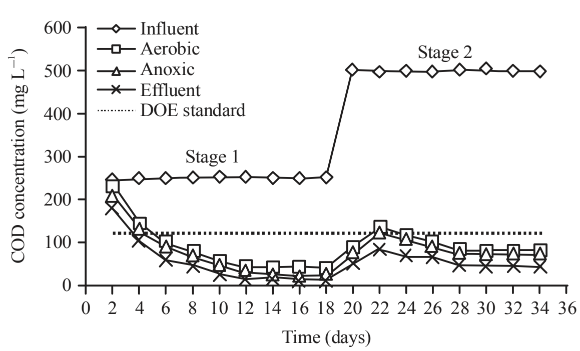

Fig. 1: Effect of organic matter

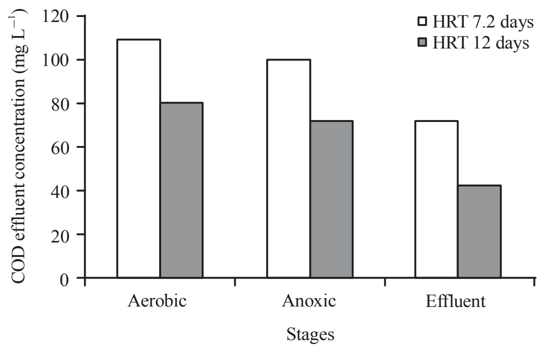

Fig. 2: Effect of HRT at steady state

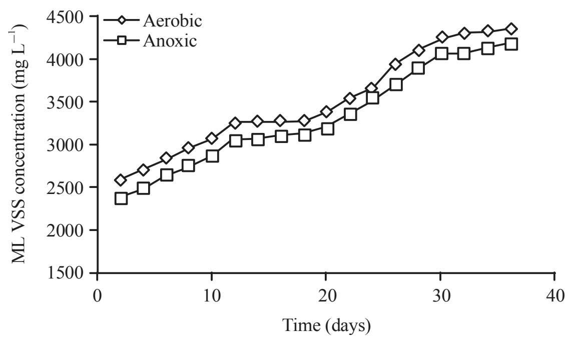

Fig. 3: Biomass concentration

was more of polishing. Significantly, the major activities in the bioreactor in stage 1 could be carbonaceous substrate removal and endogenous respiration whilst in stage 2, stabilization of biomass and exogenous substrate consumption was predominant (Hamoda *et al*., 1996).

Effect of HRT: Hydraulic Retention Time (HRT) was varied in the range 7.2 and 12 days for COD concentration of 500 mg L^{-1} (Fig. 2). Influence of HRT was observed in all bioreactor compartments when HRT was increased from 7.2-12 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 92 and 80 mg L^{-1}; 81 and 71 mg L^{-1} for anoxic compartment; 71 and 42 mg L^{-1} for effluent compartment. This observation is in agreement with reports elsewhere (Mann and Stephenson, 1997).

Biomass monitoring: The growth of biomass was monitored in the aerobic and anoxic compartment respectively (Fig. 3). It was observed that biomass growth stunted at steady state of stage 1 for both aerobic and anoxic compartments. This could be attributed to endogenous respiration at substrate saturation point. However, at steady state of stage 2, biomass was considerably in exogenous substrate utilization and microbial population increased in both compartments (Hamoda *et al*., 1996).

The growth of biomass was more significant in the aerobic compartment more than in the anoxic compartment. This could be attributed to substrate utilization and concentration gradient for both compartments. Similar observation has been reported elsewhere (Ramos *et al*., 2007).

Substrate utilization for aerobic and anoxic compartments was observed to vary. The substrate utilization for anoxic compartment (0.1725 day^{-1} m^3 kg^{-1}) was inferior compared to the aerobic compartment (1.1919 day^{-1} m^3 kg^{-1}). This could be due to the concentration gradient in both compartments.

The pH of the various bioreactor chambers were monitored and was found to be in the range 7.5, 7.3, 7.9, 7.1 for the influent, aerobic, anoxic and effluent compartments.

Ammonia was oxidized in the aerobic compartment and a 94% removal was achieved at steady state from initial concentration of 27 mg L^{-1}. Nitrate was produced from the oxidation of ammonia in the aerobic compartment and was utilized in the anoxic compartment through mass transfer from the aerobic compartment. A nitrate removal of about 84% was achieved at steady state.

CONCLUSION

The Integrated Bioreactor (IB) in this study demonstrated effective COD removal from wastewater at increased organic loading and HRTs. The final COD concentration in the effluent at the organic loadings of 250-500 mg L^{-1} were 11 and 42 mg L^{-1} whilst 71 and 42 mg L^{-1} at HRT of 7.2 and 12 days. There was no significant increase in removal efficiency in the aerobic compartment at COD concentration of 250-500 mg L^{-1} but removal efficiency decreased from 90-86% in the anoxic compartment at COD concentrations of 250-500 mg L^{-1}. Ammonia and nitrate were significantly removed (94 and 84%) respectively. Biomass growth was more significant in the aerobic compartment due to substrate utilization. The integrated baffled bioreactor has the potential to replace conventional COD removal processes as demonstrated in this study.

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