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Performance of an expanded granular sludge bed (EGSB) reactor coupled with anoxic and aerobic bioreactors for treating poultry slaughterhouse wastewater

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Abstract

Generally, slaughterhouses have the largest consumption of fresh water and thus generate large quantities of high strength wastewater, which can be treated successfully using low cost biological treatment processes. In this study, the feasibility of using an expanded granular sludge bed (EGSB) anaerobic reactor coupled with anoxic and aerobic bioreactors for the treatment of poultry slaughterhouse wastewater was investigated. The poultry slaughterhouse was characterized by high chemical oxygen demand (COD), 2 to 6 g/L, with average biological oxygen demand of 2.4 g/L and average fats, oil and grease (FOG) being 0.55 g/L. A continuous EGSB anaerobic reactor was operated for 26 days at different hydraulic retention times (HRT), i.e. 7, 4, 3 days, and organic loading rates (OLR) of 0.5, 0.7 and 1.0 g COD/L.day, respectively, to assess the bioremediation of the poultry slaughterhouse wastewater. The average COD removal from the EGSB was 40%, 57% and 55% at the different OLR and HRT assessed. At high OLR of 1.0 g COD/L.day, the overall COD removal from the system (EGSB-anoxic/aerobic) averaged 65%. The system experienced periodical sludge washout during high FOG and suspended solids loading. It was concluded that the EGSB system requires a dissolved air flotation system, for FOG/suspended solid reduction, as the performance of the overall system was observed to deteriorate over time due to the presence of a high quantity of FOG including suspended solids.

Key words: chemical oxygen demand, denitrification, expanded granular sludge reactor, fats, oil and grease, nitrification, poultry slaughterhouse wastewater

INTRODUCTION

The generation of wastewater from slaughterhouses has become an environmental concern due to the growth of the poultry industry, as demand for poultry products has increased (Debik & Coskun 2009). Poultry slaughterhouses consume significant quantities of fresh water during slaughtering and cleaning of surfaces, resulting in the generation of a significant quantity of high strength wastewater (Debik & Coskun 2009), containing high organic matter, with high nitrogen and phosphorus constituents (Avula *et al.* 2009). The high phosphorous concentration is due to blood, cleaning and sanitizing agents, and the phosphorous is in the form of organic or inorganic phosphates (Arvanitoyannis & Ladas 2008; Avula *et al.* 2009). Furthermore, slaughterhouse wastewater contains a high quantity of biodegradable organic matter with a biological oxygen demand (BOD_5) range of 1.2 to 2.6 g/L, with the soluble fraction of the BOD, ranging between 40 to 60% (De Nardi *et al.* 2008, 2011). The

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primary pollutants contributing to the BOD in the poultry slaughterhouse wastewater are insoluble proteins from carcass debris, blood, fats, including non-biodegradable matter from feathers (Avula *et al.* 2009; Manjunath 2000; Yordanov 2010). The wastewater predominantly contains 35% more protein, resulting in a much higher BOD and COD, as compared to municipal sewerage (Zhang *et al.* 2008; Avula *et al.* 2009). Therefore, the poultry slaughterhouse wastewater should be treated efficiently prior to disposal to receiving fresh water sources to reduce environmental pollution (Debik & Coskun 2009).

Biological anaerobic treatment technology is one of the most recommended treatment methods worldwide in the treatment of wastewater from the food industry due to the technology's ability to treat high strength wastewater (Karnchanawong & Phajee 2009). Numerous research studies have focused on the application of a biological anaerobic digester for the treatment of poultry slaughterhouse wastewater (Avula *et al.* 2009). The feasibility of using a multi-stage process with an expanded granular sludge bed (EGSB) anaerobic digester coupled with anoxic and an aerobic reactor was examined in this study. Anaerobic digestion has been used in treating poultry slaughterhouse wastewater as it can efficiently handle variations in particulate matter and fats, oil and grease (FOG) loading rates. Anaerobic bioreactors such as an up-flow anaerobic sludge bed (UASB) reactor have been successfully used to treat poultry slaughterhouse wastewater. Del Nery *et al.* (2007) obtained treatment efficiency rates of 65% for total COD and 85% for soluble COD reduction at an average organic loading rate (OLR) of 1.64 kg COD/m^3.day using a full scale UASB reactor. Similarly, (Debik & Coskun 2009) used a static granular bed reactor (SGBR) to treat the poultry slaughterhouse wastewater, achieving averaged COD removal rates of 95%. Similarly, the EGSB, which is well known to increase sludge expansion for improved efficiency due to its recirculation stream, was reported to achieve COD removal of 67% by Nunez & Martinez (2009), treating poultry slaughterhouse wastewater without a pretreatment process.

In this present study, a two-stage process containing an EGSB anaerobic digester coupled with anoxic and aerobic bioreactors was proposed to treat poultry slaughterhouse wastewater from a poultry product manufacturer in South Africa. From a South African perspective, the use of such a system has not been applied on an industrial scale, particularly for the treatment of poultry slaughterhouse wastewater. Therefore, this study was conducted to assess the performance of the bench-scale EGSB anaerobic bioreactor coupled with anoxic and aerobic bioreactors in treating the poultry slaughterhouse wastewater, to meet municipal discharge standard in South Africa.

MATERIALS AND METHODS

Experimental set-up and equipment

The laboratory bench-scale system was operated in a two-stage process consisting of an EGSB reactor followed by the anoxic and aerobic bioreactors (see Figure 1). The system was operated over a period of 26 days.

The EGSB laboratory bench-scale reactor set-up

The purpose of the EGSB reactor was to effectively reduce the organic load of the feed subsequent to the effluent being treated in the anoxic and aerobic bioreactors. The EGSB consisted of a cylindrical-shaped vessel with a total working volume of 1.2 L with a height and inner diameter of 0.22 m and 0.06 m, respectively. The reactor consisted of a gas–liquid separator at the top of the column for the separation of solids and biogas from the liquid phase. The biogas produced from the EGSB reactor was collected at the top of the reactor using Tedlar bags. The influent was pumped continuously and

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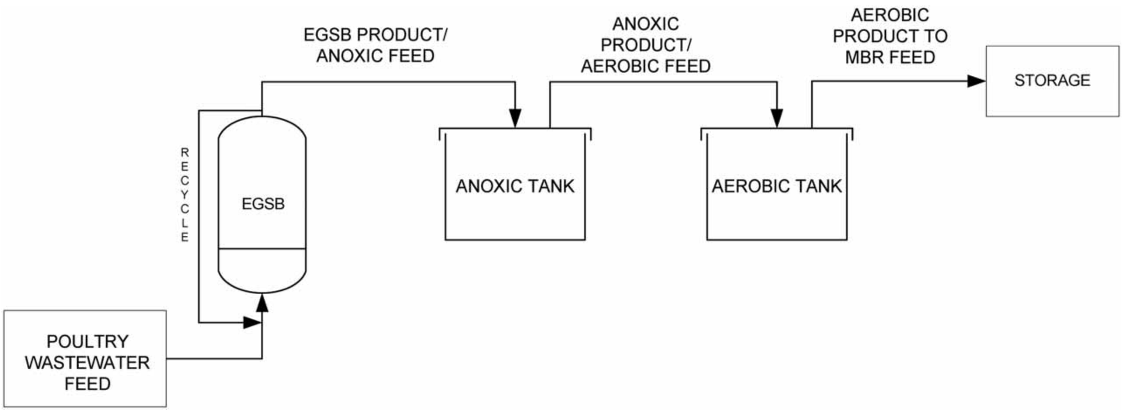

Figure 1 | Schematic diagram for the laboratory bench-scale EGSB, anoxic and aerobic bioreactor system.

fed from the bottom of the reactor using a Gilson (Germany) peristaltic pump and the effluent was withdrawn from the top. The effluent liquid phase was split into two streams: (i) EGSB product and (ii) the recirculation stream. The recirculation stream from the top was mixed with the fresh effluent feed to the EGSB reactor. The liquid up-flow velocity was maintained at 1.1 m/hr. The reactor operated at a constant temperature of 37 °C, temperature regulated using a water jacket through which water from a thermostatic waterbath circulated. The reactor was also insulated to prevent heat losses to the environment.

The anoxic and aerobic bioreactor set-up

The purpose of the anoxic tank and aerobic systems was for denitrification and nitrification processes, respectively. The anoxic and aerobic systems had a working volume of 0.825 L. The anoxic tank was placed on a magnetic stirring plate for continuous homogenization of the contents. The aerobic tank had two miniature air-diffusers with air supplied at a flow rate of 1.9 L/min.

Slaughterhouse wastewater

The poultry wastewater was collected from an slaughterhouse located in the Western Cape Province, South Africa. The characteristics of the wastewater are summarized in Table 1, which lists averaged values of parameters quantified over a 3 week sampling period. All measurements were performed according to Standard Methods (APHA 2005).

Seed preparation

The inoculum used for the EGSB was prepared as a mixture of 0.3 L granular sludge taken from a full-scale up-flow anaerobic-sludge bed (UASB) reactor treating brewery effluent (SABMiller, Newlands Brewery, South Africa) and 0.1 L of digested sewage sludge taken from a municipal wastewater treatment plant (City of Cape Town, South Africa). The anoxic and aerobic bioreactors were inoculated with 0.0825 L of digested sewage sludge and 0.7425 L of the poultry slaughterhouse wastewater.

EGSB operating conditions

During the start-up phase, the laboratory bench-scale EGSB was operated at an hydraulic retention times (HRT) of 7 days and an OLR of 0.5 g COD/L.day. Thereafter, the HRT was decreased each week to 4 days, and subsequently to 3 days, with OLR being increased to 0.7 g and 1.0 g COD/L.day, respectively.

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Table 1 | Characteristics of the wastewater from an industrial slaughterhouse in the Western Cape, South Africa

		Poultry slaughterhouse waste water	
Parameter	**Unit**	**Range**	**Average**
pH	–	6.5–8.0	6.88
Alkalinity	mg/L	0–489	489
TCOD	mg/L	2,133–4,137	2,903
SCOD	mg/L	595–1,526	972
BOD5	mg/L	1,100–2,750	1,667
TKN	mg/L	77–352	211
Ammonia	mg/L	29–51	40
TP	mg/L	8–27	17
FOG	mg/L	131–684	406
TDS	mg/L	372–936	654
TSS	mg/L	315–1,273	794
VSS	mg/L	275–1,200	738
Soluble proteins	mg/L	0–368	72
VFA	mg/L	96–235	235
Nitrates	mg/L	0–2,903	2,903

Analyses of poultry slaughterhouse industrial wastewater

Twenty five litres of fresh poultry slaughterhouse effluent was received every week and was analysed for pH, TDS, BOD, COD, NH_4^+, TSS, TP, FOG and NO_3^-. A sample was also sent to an independent accredited laboratory (Scientific services, City of Cape Town, SA) for full chemical analysis, for comparative analysis.

Combined EGSB-anoxic-aerobic system operational scheme and monitoring

Analyses of the EGSB feed, EGSB product, anoxic and aerobic bioreactors product streams were monitored to assess the performance of the whole system, with values of parameters such as the chemical oxygen demand (COD), pH, being analyzed every 48hrs.

RESULTS AND DISCUSSION

The system was started at an HRT of 7 days and OLR of 0.5 g COD/L.day to maintain start-up operating conditions, which provided the necessary acclimatization time for biomass and system stability. During the first week of operation, the EGSB experienced sludge washout due to high FOG and suspended solids loading in the feed. The sludge washout inhibited the EGSB performance. The following sub-sections describe and discuss the results obtained in the study.

Variation of OLR and HRT on the EGSB reactoralinity tolerance test

The EGSB-anoxic-aerobic system was continuously operated for a period of 26 days at different HRT and OLR. The HRT of the EGSB was maintained at 7 days during the start-up period and maintained at this rate for a period of one week. The HRT was thereafter decreased step-wise to 4 days, which was further reduced to 3 days, respectively–see Figure 2. Figure 2 also showed variation of the OLR, which ranged from 0.2 to 2.2 g COD/L.day. The up-flow velocity in the EGSB was kept constant at 1.1 m/hr.

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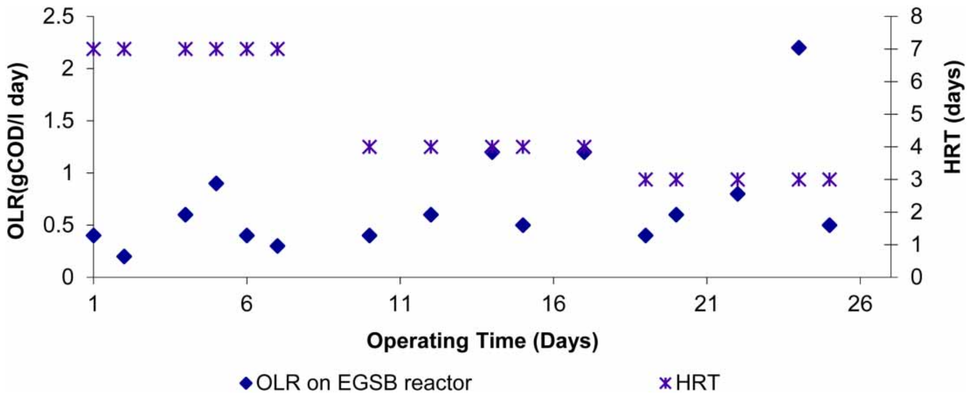

Figure 2 | Variation of OLR and HRT during experimental studies.

The COD in the feed ranged between 2,133 to 4,137 mg/L with an averaged COD of 2,903 mg/L. The COD was used in this study as a comparative parameter to quantify system performance and to monitor the effect of the OLR throughout the study.

EGSB performance and COD removal

The average COD removal was observed to be 40%, 57% and 55% at phase 1, phase 2 and phase 3 respectively, as shown in Figure 3. The average COD removal in the EGSB was found to be 51%. It was observed that the COD percentage removal decreases at the highest OLR (phase 3) of 1.0 g COD/L.day. This was attributed to the high feed flow rate to the EGSB, including high FOG loading, present in the feed, including the overall residence time of the poultry wastewater, within the EGSB. Furthermore, FOG generally increases sludge washout, which lowers reactor efficiency particularly for any anaerobic reactor. In a study conducted by Miranda *et al.* (2005), it was reported that an influent FOG/COD ratio above 20% has a detrimental effect on a full scale UASB reactor, resulting in biomass washout and therefore system failure. The performance of the UASB reactor was reported to have improved at an FOG/COD ratio of 10%.

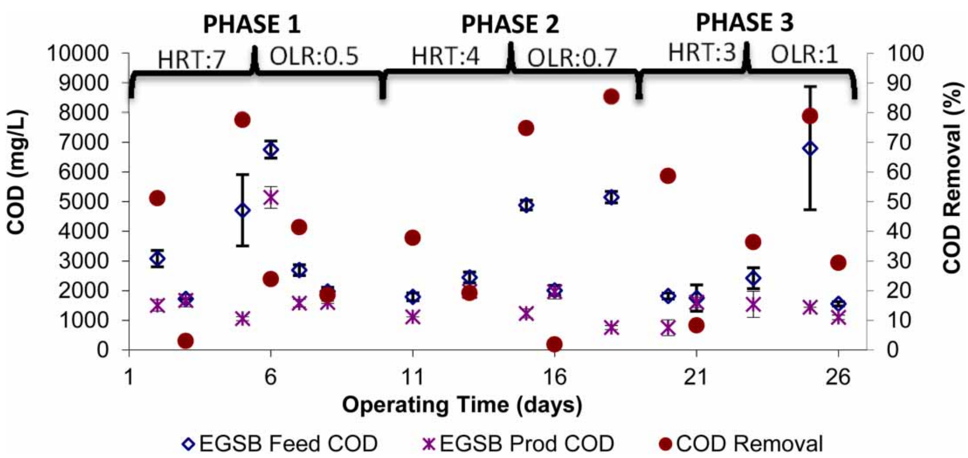

Figure 3 | Variation of COD concentration at different OLR and HRT and COD removal efficiency on the EGSB reactor.

Overall COD removal of the EGSB, anoxic and aerobic

Figure 4 illustrates the overall COD removal efficiency of the system. This was determined from the inlet effluent (i.e. EGSB feed) and the final exit effluent from the aerobic tank. The overall average

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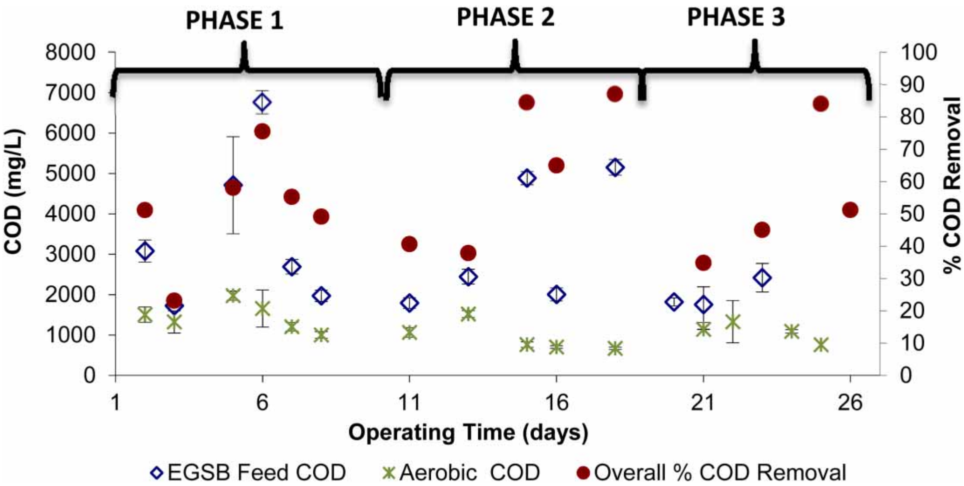

Figure 4 | Variation of COD concentration at different OLR, HRT and COD removal efficiency.

COD removal of the system was 65%. As shown in Figures 3 and 4, the data shows 63% COD removal being its highest during the second operating phase. The average overall COD efficiencies for Phase 1 and Phase 3 were 52% and 53%, respectively. The low COD removal was due to periodical sludge washout on the anaerobic digester or pipe blockages due to accumulation of fats on the feed line resulting in reduced feed flow rate. Furthermore, reduced anaerobic feed flow rate can result in the secondary system (anoxic and aerobic) wash out due to lower flow rate out of the EGSB. This led to the re-inoculation of the secondary system, hence reducing the overall efficiency of the system.

Varition in pH

The pH was used to monitor the stability of the EGSB reactor, anoxic and aerobic tank as depicted in Figure 5. The EGSB feed and EGSB product were stable at a range of 6.5 to 8 throughout the study, which is the optimal condition for methanogens activity. The pH of anoxic and aerobic tank was at a range between 5 to 8. The results also indicate the pH drop below 6 for the EGSB feed, anoxic and aerobic tank between day 17 and 23 of operation.

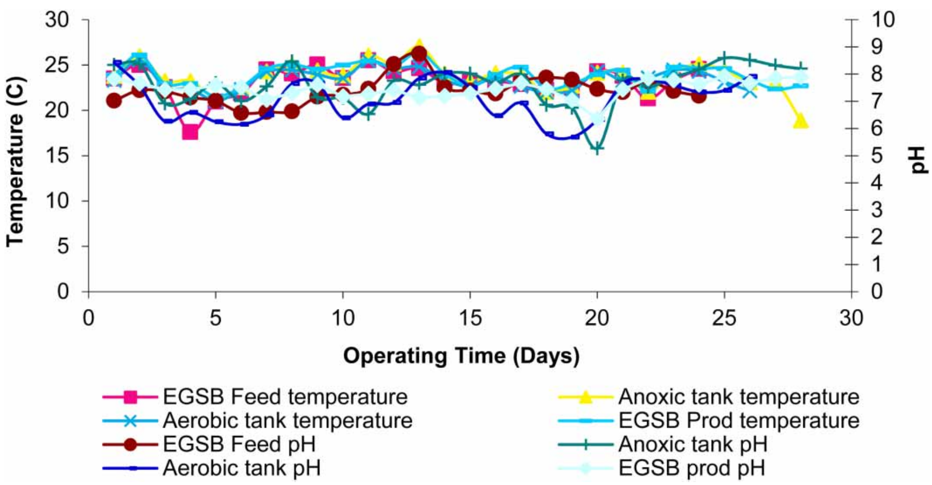

Figure 5 | Variation of pH during operation.

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CONCLUSION

The laboratory bench-scale EGSB anaerobic digester coupled with anoxic and aerobic activated sludge tank was used for this study to treat poultry slaughterhouse wastewater. Poultry slaughterhouse wastewater was treated at different HRT and OLR. The overall COD reduction for the system was 65%. The average EGSB reactor COD efficiency was 51%. The poor performance of the EGSB reactor was contributed to high FOG and suspended solids in the influent, which result in sludge washout and decrease in methanogenic activity. Sludge washout might have been the main contributor for poor biogas production in the EGSB reactor, as the methanogens floated out of the system. Due to reduce influent flowrate and sludge reduction during operation of the EGSB reactor, this study recommends that a pre-treatment system such as a Dissolve Air Flotation system be used to reduce the suspended solids and FOG in the feed. This will be beneficial to the performance of the EGSB reactor and thus improve its performance.

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