Performance and Statistical Comparison of the Expanded and Static Granular Sludge Bed Reactors Treating Poultry Slaughterhouse Wastewater

E. Kaskote, M. Basitere, S.K.O Ntwampe and M. Njoya

***Abstract*—**Poultry slaughterhouse wastewater (PSW) is characterized by high organic pollutant levels. High rate anaerobic digesters are effective and economical in treating such effluent, removing pollutants at low cost. In this study, the performance of the static granular bed reactor (SGBR) and expanded granular sludge bed (EGSB), were compared. The bioreactors were used to treat PSW from the Western Cape, South Africa. Their performances were compared at hydraulic retention times (HRTs) of 55, 48 and 36 hrs, and organic loading rates (OLRs) between 0.62 and 5.1 g-COD/L/day. The SGBR achieved an average COD removal of 78%, while the EGSB achieved 66%. The SGBR and EGSB's TSS removal efficiencies were 86% and 89%, respectively. The SGBR's COD removal efficiencies at 55- and 36- hr HRTs were 70 and 87%, respectively. Both were better than that of the EGSB at the same HRTs. At 48-hr HRT, however, there was minimal statistical difference in efficiency between them. There was no significant statistical difference between the two reactors in TSS removal efficiency at the various HRTs.

***Keywords*—**Expanded Granular Sludge Bed Reactor; Hydraulic Retention Time, Organic loading rate; Static Granular Bed Reactor; Poultry Slaughterhouse Wastewater

I. Introduction

Recently in South Africa, the poultry industry has grown exponentially due to increasing demand. The growth continues and is associated with the consumption of large volumes of potable water for bird cleaning and processing. PSW is laden with organic matter originating from blood, meat trimmings, undigested food and feathers [6]. Potential environmental effects of the discharge of untreated PSW into surface water bodies are eutrophication [17] and groundwater contamination [20]. Chan et al. [4] and Rajakumar et al. [18] report that highly polluting industrial effluents can be treated using anaerobic systems, as their organic matter content is suitable and that this culminates in the production of biogas, an alternative energy source, with less sludge produced than from aerobic processes.

Numerous research studies have focused on the application of anaerobic digesters such as the expanded granular sludge bed (EGSB) and the static granular bed reactors (SGBR) to the treatment of PSW. The EGSB is a variant of the up-flow anaerobic sludge blanket (UASB) reactor, and is suitable for the treatment of low to high strength wastewaters, or those containing inert or poorly biodegradable organic matter that may accumulate in the biodigester. The SGBR is a simplified, high-rate, anaerobic granular system, developed to provide high performance efficiency while reducing bioreactor operating costs arising from design and/or fabrication complexity [10];[16]. Unlike the EGSB, which is operated in up-flow configuration, the SGBR is down-flow configured and relies on a granular biomass retained by an underdrain. The SGBR has lower energy requirements than the EGSB and has been shown to be able to treat PSW, with COD removal efficiency exceeding 95% [6]. Working with an ESGB reactor, Núñez. and Martínez [14] reported that it achieved 67% COD removal from PSW without a pre-treatment system. Cruz-Salomón et al. [5] obtained maximum COD removal efficiencies of 91, 74, and 96% when treating cheese whey, vinasse, and coffee processing wastewaters, respectively. A pilot-scale SGBR used by Roth [19] to treat pork slaughterhouse wastewater achieved COD removal efficiency exceeding 90%. Similarly, Mach et al. [11] showed that an SGBR could treat sulphate-containing wastewater for more than a year with COD removal exceeding 90%. Furthermore, Biese [3] used an SGBR to treat primary and secondary sludges and obtained a COD removal efficiency exceeding 90%.

The main objective of this study was to compare the performance of the SGBR and EGSB reactors statistically in treating PSW, determine suitable treatment options under differing HRTs and OLRs. The analyses were used to elucidate the similarities and differences between the two reactor types. The SGBR is an innovative treatment process for low to medium strength wastewaters and is reported to yield an effluent containing low COD, VFA and TSS concentrations [10].

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II. Materials And Methods

A. Inoculum And Wastewater Characteristics

The PSW was collected from a poultry slaughterhouse in Cape Town, Western Cape Province, South Africa and refrigerated (4°C) prior to experimental use. Both the SGBR and EGSB reactors were inoculated with granular sludge from a full-scale UASB treating brewery effluent at a South African brewery (SAB Miller Plc, Newlands, South Africa). A dry milk solution was introduced into the bioreactors as a carbon source for the anaerobic biomass and to facilitate the inoculum's acclimation. The dry milk solution contained 2000 mg-COD/L.

B. Reactor Set-Up And Operation

Two cylindrical glass reactors were constructed with identical working volumes (2.33 L) for the EGSB and SGBR (Fig. 1) reactors. The EGSB headspace comprised a phase separator to separate the product from the biogas and the flocculating sludge. Recirculation was used in the EGSB to control the reactor's water up-flow velocity, while pumice was used at the bottom as an underdrain and to assist – i.e., improve wastewater distribution.

The SGBR is broadly similar to the EGSB, but the influent enters at the top of the reactor through the inlet flow distribution system and flows downward by gravity through the bed of active anaerobic granules. The downflow operation allows the influent to be mixed with the bulk liquid by the counter-current flow of biogas and liquid. It was backwashed to remove suspended solids affecting the system when required – e.g., after clogging.

Influent was fed into the reactors using a multi-channel Gilson (Germany) peristaltic pump. The reactors operated at 40 °C, which was maintained consistently by a water jacket and water bath system. A tedlar – polyvinyl fluoride – bag was connected to the top of each reactor to collect the biogas produced.

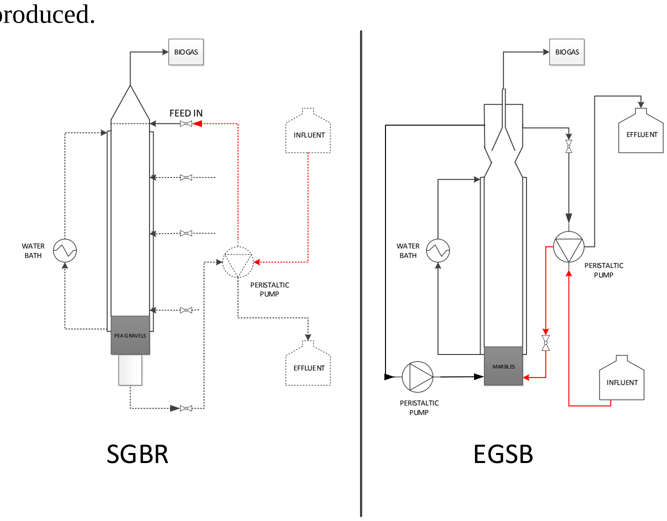

Fig. 1 Experimental set up

C. Analytical Methods

Total suspended solids (TSS) were measured using ESS method 340.2 [7]. Total dissolved solids (TDS) were determined with a PSCTestr 35 multi-parameter unit (Eutech Instruments). Turbidity was quantified with a Turbidimeter TN-100 (Eutech Instruments). COD was determined using a Merck Spectroquant® NOVA 60 and Merck solutions A (1.14679.0495) and B (1.14680.0495). The results were verified by the City of Cape Town's Scientific Services Laboratory (Cape Town, South Africa) according to the American Public Health Association (APHA) standards [1].

III. Results And Discussion

A. Performance Capacity

The performance capacity of the SGBR was compared to that of the EGSB at HRTs of 55, 48 and 36 hrs. The SGBR removed COD better at HRTs of 55 and 36 hrs, with average removals of 78% compared to 66% for the EGSB. No significant performance differences were observed between the SGBR and EGSB at 48-hrs HRT for either COD or TSS removal. The results also indicated that, at lower HRTs, ESGB performance decreased due to sludge wash-out arising from the increased flow rate.

TABLE I Results Summary For The SGBR And EGSB

Operating period	HRT (hours)	Parameter (Units)	SGBR			EGSB		
			Influent	Effluent	Efficiency (%)	Influent	Effluent	Efficiency (%)
Days 0 to 40	55	**pH**	6.92	8.15	NA	6.87	6.87	NA
		COD (mg/L)	2606	766	70	4221	1485	62
		TSS (mg/L)	375	56	80	1123	62	93
		VSS (mg/L)	658	391	NA	1325	416	NA
		Turbidity (NTU)	372	14	96	701	36	95
		NO_3-N (mg/L)	0.54	3.52	NA	0.87	9.40	NA
		NH_4-N (mg/L)	110	170	NA	153	84	NA
Days 40 to 80	48	**pH**	6.90	7.69	NA	6.41	7.76	NA
		COD (mg/L)	3871	821	77	7707	1285	81
		TSS (mg/L)	1349	79	89	3447	233	92
		VSS (mg/L)	2179	628	NA	22414	1145	NA
		Turbidity (NTU)	694	10	98.5	705	31	95.5
		NO_3-N (mg/L)	2.70	16.91	NA	5.84	0.18	NA
		NH_4-N (mg/L)	193	192	NA	251	229	NA
Days 80 to 120	36	**pH**	6.49	7.62	NA	6.38	7.74	NA
		COD (mg/L)	7155	788	87	7972	1585	79
		TSS (mg/L)	2588	69	94	2098	292	71
		VSS (mg/L)	3412	971	NA	869	1168	NA
		Turbidity (NTU)	858	7	99	743	65	91
		NO_3-N (mg/L)	4.86	16.69	NA	2.88	0.87	NA
		NH_4-N (mg/L)	230	178	NA	199	203	NA

B. Organic Loading Rates

The SGBR and the EGSB were operated continuously for 16 weeks at different HRTs and OLRs. COD and TSS were selected to compare reactor performance and monitor the effect of OLR throughout the study. During sludge acclimation, PSW diluted 50% with tap water and was fed to the reactors to avoid shock loading. Thereafter, influent strength was increased to 25% dilution and, later, the feed was undiluted. OLR variations in the SGBR and EGSB influents during the study are shown in Fig. 2.

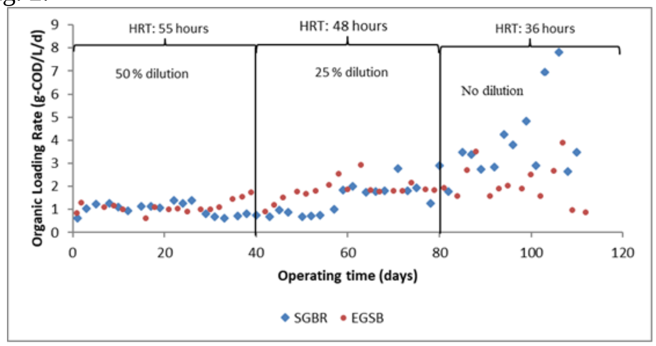

Fig. 2 Variation of Organic Loading Rate

OLR variations in the SGBR and EGSB influents during the study are shown in Fig 2. The OLR ranged from 0.62 to 5.32 g-COD/L/day in both reactors. Influent COD concentrations in the same period ranged between 1,422.5 and 11,708 mg/L for both reactors.

C. SGBR, EGSB: COD Removal

Fig. 3(a) and 3(b) illustrate the COD concentration and removal efficiencies of the two reactors at different HRTs (n = 3). In the first phase the HRT was 55 hrs, while, in the second and third phases, the HRTs were 48 and 36 hrs, respectively. The average COD removal efficiencies of the SGBR were 70, 77 and 87% during the three HRT phases, and those of the EGSB 62, 81 and 79%, respectively. The effluent COD concentrations from the reactors were similar despite the influent COD variation.

The EGSB's COD removal efficiency increased with increasing OLR concentration. This may be attributed to the ESGB's consistent effluent quality, even though the influent COD concentration was changing as the OLR increased, leading to higher COD removal efficiency. The quality of the effluent indicated the stability of the reactors. Furthermore, the anaerobic biomass responded better to environmental fluctuations and was suited to the ESGB's low influent flow rate. This was confirmed by Miranda et al. [12], who reported that an influent Oil and Grease/COD ratio above 20% is detrimental in full-scale UASBs, resulting in biomass washout and system failure.

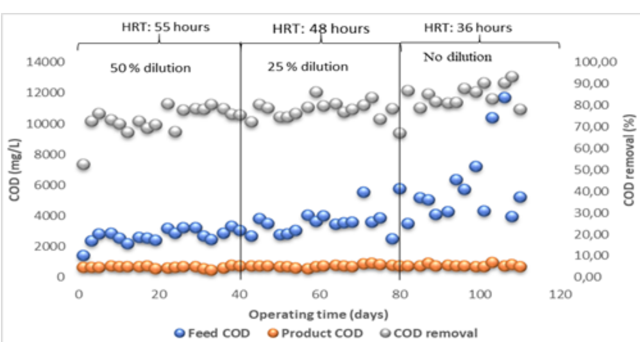

Figure 3(a) COD concentration and COD removal (%) of the SGBR

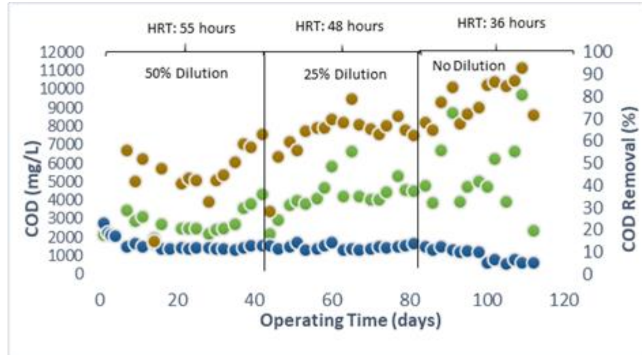

Fig 3(b) COD concentration and COD removal (%) of the EGSB

D. SGBR, EGSB: TSS Removal

Fig. 4(a) and 4(b) show the TSS removal efficiencies of the two reactors. Both achieved high TSS efficiencies – between 71 and 94% – during the trial, Oh et al. [16] reported TSS removal exceeding 80% for an SGBR treating dairy wastewater at ambient temperature, while Núñez. and Martínez [14] reported TSS removal of 90% treating slaughterhouse wastewater using an EGSB. Despite the variation in influent TSS concentration for the two reactors, they achieved consistent TSS removal. Basitere et al. [2] note that the SGBR's effluent TSS concentration depends on both the anaerobic digestion process and the physical processes retaining suspended solids in the granular bed, which acts as a biofilter. Because of this, the SGBR's down-flow operation contributes to TSS removal as the granular bed and pea gravel act as a filter.

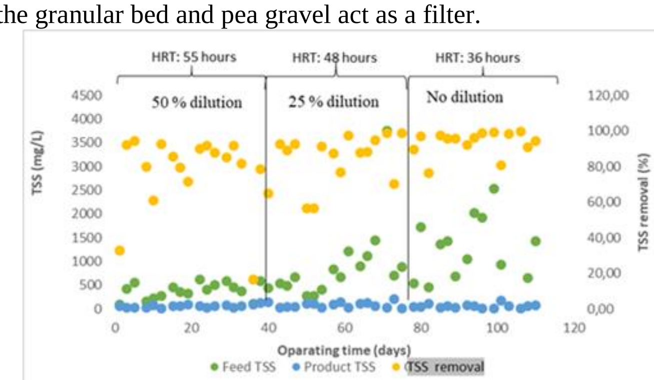

Figure 4(a) TSS and TSS removal (%) of the SGBR

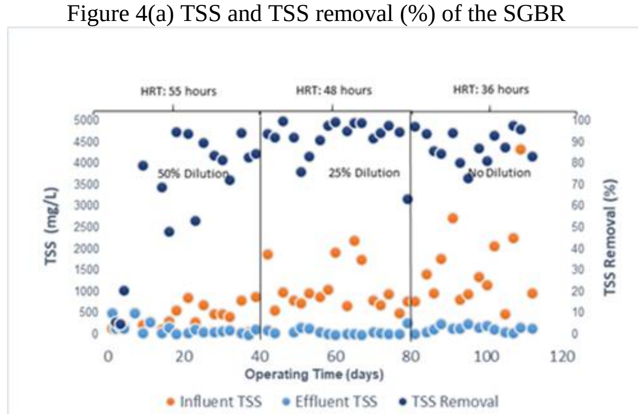

Figure 4(b) TSS and TSS removal (%) of the EGSB

E. Statistical Comparison Of SGBR And EGSB Reactor Performance

Statistical analysis was used to establish the significance of the differences in performance of SGBR and EGSB, in COD and TSS removal efficiency at different HRTs. A paired T-test for means was used to determine whether the difference is genuine or could just have been chance. The test is generally used to compare pairs of means and determine whether they differ within a specified degree of certainty, the higher the T-value, the more certain the differentiation of the systems compared.

TABLE II STATISTICAL ANALYSIS FOR COD REMOVAL BETWEEN SGBR AND EGSB

HRT (hrs)	*Degrees of freedon*	*T-stat*	*T-critical*	*P-value*
55	11	2.506	2.20	0.0292
48	5	0.390	2.57	0.712
36	5	5.954	2.57	0.00191

TABLE III STATISTICAL ANALYSIS FOR TSS REMOVAL BETWEEN SGBR AND EGSB

HRT (hrs)	*Degrees of freedom*	*T-stat*	*T-critical*	*P-value*
55	11	-2.51	2.57	0.574
48	5	-0.6	2.57	0.574
36	4	1.204	2.78	0.294

At 55 hrs HRT for COD removal, the T-stat (2.506) exceeded the T-critical (2.20) – i.e., there was a real difference between the SGBR and EGSB means (see TABLE IV). As the p-value (0.0292) is less than 0.05, the null hypothesis, that there is "minimal difference between the two means", could be rejected. Similar results were found at 36 hrs HRT, but there is a difference between the SGBR and EGSB results at HRTs of 55 and 36 hrs. At 48 hrs HRT, T-stat (0.390) was below T-critical (2.57) and the P-value exceeded 0.05, in other words, the difference between the two means was insignificant.

The results of the parallel statistical analysis for TSS removal are shown in TABLE V . The P-value exceeded 0.05 for all three HRTs, meaning that there was insignificant differentiation in the reactors' TSS removal means or minimal TSS removal differentiation.

IV. CONCLUSION

The SGBR's performance capacity was compared to that of ESGB at HRTs of 55, 48 and 36 hrs. The SGBR was shown to perform similarly to other high-rate anaerobic systems, and thus be potentially viable as a wastewater treatment alternative. Insignificant performance differences were observed between SGBR and EGSB, however, at 48 hrs HRT, for both COD and TSS removal. It was also found that, as the HRT decreased, ESGB performance decreased which minimized the PSW and granular sludge contact time. In general, the SGBR performed similarly to other high-rate anaerobic systems and is, therefore, a viable wastewater treatment option for the South African poultry industry.

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