Abattoir effluent treatment and protein production: Full-scale application[#]

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Abstract

A modified sequencing batch reactor (SRB) process was evaluated at full scale for the pretreatment of abattoir effluent and for the production of protein that can be used as an animal feed supplement. Successful pretreatment was achieved with unfiltered COD removal in excess of 90% and filtered COD of less than 200 mg/ℓ. The process adapted readily to variation in effluent volume, flow rate and duration, and was self-regulating. The peak oxygen supply, and therefore power requirements, was reduced by incorporating an anoxic phase during the Fill period. The biomass produced had a crude protein value of c. 40% and was successfully used as a supplement to carcass meal for animal feed. An economic feasibility study showed a net income from protein sales compared to running expenses and a major saving on effluent tariffs, recovering all expenses within the first year of operation. Comparison of the results with those of a previously completed pilot-plant study, showed differences, emphasising the importance and risk involved in scale-up.

Introduction

The abattoir industry in South Africa produces approximately 6 x 10^6 kℓ effluent per year with a chemical oxygen demand (COD) of 30 000 t/a (WRC, 1990; Cowan, 1994). Most of the effluent ends up in a municipal network resulting in high tariffs payable to the local authority for the receipt and purification thereof. This forces the bigger abattoirs to seek alternatives for effluent treatment and to consider recovery of by-products (Van der Westhuizen and Pretorius, 1996) and the reuse of effluent (Cowan, 1994; Roux and Pretorius, 1997).

Physico-chemical treatment of abattoir effluent for the recovery of high-quality reusable water has successfully been tested on pilot-plant scale (Roux and Pretorius, 1997; WRC, 1998). Biological pretreatment is also possible with the potential of protein as a commercial by-product (Waslien and Steinkraus, 1980; Van Niekerk, 1985; Couillard and Zhu, 1993). De Villiers and Pretorius (2000) reported the successful biological pretreatment of an abattoir effluent in a 60 m^3 pilot plant. The study evaluated a modified sequencing batch reactor process that was easy to operate and adapted readily to changes in raw effluent generation. A biomass was produced with a low sludge volume index (SVI) (50 to 75 mℓ/g) that could be used as a supplement to carcass meal for animal feed. The biomass had a crude protein value (CP) of between 27 and 37% which was cell residence time (θ_c) dependent.

Subsequent to the pilot-plant study the process was implemented at full scale at an abattoir with a slaughter capacity of 2 000 cattle units per day. The evaluation of the full-scale implementation is reported here. The aim of the study was to assess at full scale the modified SBR process for pretreatment of the abattoir effluent and to evaluate the feasibility of the full-scale application.

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Materials and methods

Modified SBR process. The modified sequencing batch reactor (SBR) process (De Villiers and Pretorius, 2000) is defined as an SBR (Irvine and Busch, 1979) with external settler. Flow equalisation takes place within the reactor which is operated as an SBR, except for settlement which takes place in the external settler. Feed to the reactor is intermittent and Idle time is applied. It can also be described as a continuously stirred tank reactor with changing water level and cell recycle (Grady and Lim, 1980).

Full-scale plant. Existing structures were utilised and adapted to suit. A circular reactor, 46 m in diameter and 3.5 m deep, with floating mechanical aerators was used. A single secondary settling tank (SST) was used, 20 m in diameter with the feed pumped (reactor pump) from the reactor and the recycle gravitated back. The recycle flow was controlled with a telescopic valve. The final effluent was stored in a holding tank for overnight release (refer to Fig. 1).

Substrate. Substrate included all the industrial streams: process, offal, lairages and by-products, but excluded sewage. Screening of the different streams (Table 1) and fat removal were implemented as primary treatment. Effluent generation depended on the number of animals slaughtered, with weekends normally being non-slaughter days.

TABLE 1
Screen type and aperture

Effluent stream	Screen type	Aperture (mm)
Process and by-products	Inclined fixed	0.8
Offal	Wine press	3
Lairages	Rotary	1.6

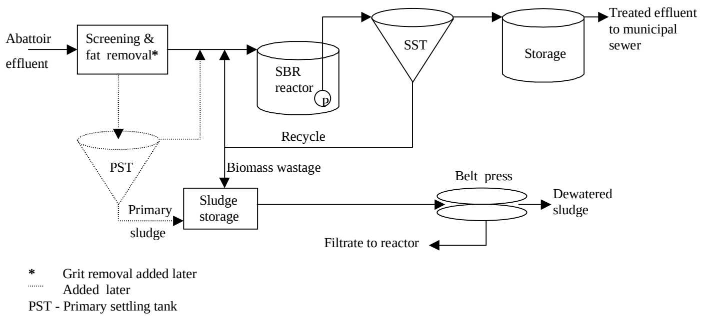

Figure 1
Process flow diagram

Operation. The plant was operated as a modified SBR system with Fill, React, Draw and Idle within the reactor, but with Settle in the settling tank (Irvine and Busch, 1979; De Villiers and Pretorius, 2000). The React period was assumed to be the period from the beginning of Fill to the beginning of Idle.

The reactor pump was reactor water-level controlled, with low level "off" and a higher level "on", and flow rate such (less than inflow plus recycle) that partial flow equalisation takes place within the reactor. Biomass was wasted from the settler underflow on slaughter days and dewatered on a belt press.

Aeration was decreased on non-slaughter days and controlled on slaughter days so that an anoxic period was partially induced during Fill, similar to the pilot-plant operation. The aerators were controlled by timers, set for typical operation. The dissolved oxygen (DO) concentration was generally controlled at levels below 3 mg/ℓ.

Test runs. Two test runs were completed; Test Runs 1 and 2 with cell residence times (θ_c) of c. 5 and 8 d respectively, while keeping other parameters constant.

Monitoring and analysis. The numbers of animals slaughtered, water consumption, effluent volume, aerators in use and reactor temperature were measured and recorded daily. DO and mixed liquor suspended solids (MLSS) were monitored on-line and recorded on computer. Samples were taken daily of the primary treated substrate, final treated effluent and mixed liquor, and analysed for total suspended solids (TSS), COD and the mixed liquor for MLSS. The settler underflow concentration and the SVI were determined daily. All analyses were done as per *Standard Methods* (1980) except where otherwise stated. The process was allowed at least three θ_c to stabilise before a complete set of analyses were done and a mass balance completed for the test day of each test run. Biomass samples were occasionally analysed for CP, determined from the total organic nitrogen, and observed for filamentous organism characterisation (FOC) by phase contrast microscopic observation (Jenkins et al., 1986). FOC was reported on a scale from 1 (none) to 6 (excessive).

Results and discussion

Start-up. The reactor was filled with primary treated substrate, the recycle flow rate and the control levels for the reactor pump were set and aeration commenced.

A fat layer developed on the reactor water level and soon impacted on the operation of the plant. The reactor had to be cleaned out, uncovering a serious build-up of suspended matter and grit. This led to a more efficient housekeeping programme within the abattoir, especially on fat removal at the by-products plant. Grit removal and primary settling with scum removal were also incorporated (refer to Fig. 1, additions). The primary sludge was dewatered on the belt press.

Build-up of fat or suspended matter was never experienced during the pilot-plant study. The study was, however, done at another abattoir with lairages and by-product effluents excluded. The build-up of suspended matter in the reactor was accredited to a higher TSS in the substrate, 1.5 to 3.5 g/ℓ, compared to the pilot-plant study, 1.1 to 2.1 g/ℓ, and to different aeration systems, coarse bubble for the pilot plant vs. floating mechanical for the full-scale plant.

This experience emphasizes the importance of completing pilot-plant work on the actual effluent planned for application, and the preference of using similar equipment.

Modified SBR operation. The operating cycle for both test runs were typically as shown in Table 2.

TABLE 2
Typical operating cycle

Mode	Time: start to stop	Duration (h)
Fill	07:00 – 16:00	9
React	07:00 – 19:00	12
Settle	08:00 – 19:00	11
Draw	08:00 – 19:00	11
Idle	19:00 – 07:00	12

The operation could be varied by adjusting the reactor pump and recycle flow rates, the reactor pump control level settings and the number of aerators operating at any time on a weekly cycle. These variables made it possible to adapt the operation to variation in effluent volume, flow rate and duration. The extent of flow equalisation could be controlled and different DO patterns induced. Once set for a typical operation, the system was self-regulating by adjustment of the duration of the fill and the settle periods due to flow equalisation in the reactor and the return to the same starting point for the consecutive daily cycle to start.

The process stabilised at an MLSS of 3 500 and 4 900 mg/ℓ with standard deviations of 300 and 400 mg/ℓ (c. 8%), for Test Runs 1

TABLE 3
Treatment efficiency: Test days

Test day results for test run	Parameter	Substrate mg/ℓ	Primary settled		Secondary settled	
			Effluent mg/ℓ	Removal %	Effluent mg/ℓ	Removal %**
1	TSS	1 785	998	44	58	97
	COD*	4 660	3 486	25	280	94
2	TSS	3 048	1 386	55	45	99
	COD*	5 859	3 434	41	245	96

* Unfiltered
** Overall removal

TABLE 4
Biomass characteristics and protein production

Test run	θ_c days	MLSS mg/ℓ	SVI mℓ/g	FOC	Biomass production* gTSS/gCOD	CP** %	Aeration Watt/m³
1	5,2	3 500	90	½	0,60	41	48
2	8,4	4 900	150	½	0,44	40	60

* Secondary sludge only
** Mixed primary and secondary sludge.

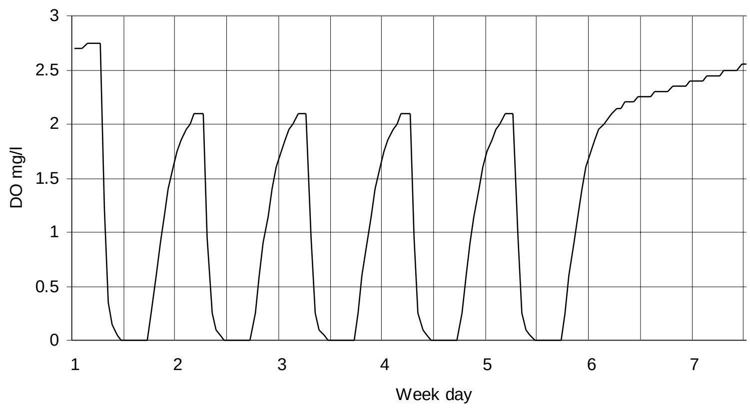

Figure 2
Approximated DO concentrations for one week

and 2, respectively. The process can therefore be described as stable, in a steady cyclic state, although it is a semi-batch process.

Treatment efficiency. The results in Table 3 are the results for the two test days after stabilisation. Overall unfiltered COD and TSS removal was in excess of 90 and 95%, respectively. The filtered COD for the final treated effluent was less than 200 mg/ℓ, approximately 5% of the primary settled COD, and can therefore be assumed to be mainly unbiodegradable. This is similar to the pilot-plant study. The TSS in the effluent was lower, compared to over 100 mg/ℓ for the pilot plant, resulting in a higher unfiltered COD removal on full scale.

The results from the test days compared well with the analysis done daily during the stabilisation periods.

Aeration and DO. Aeration was kept constant during slaughter days. The DO decreased to nil during Fill, simulating the pilot-plant trials but generally with a longer duration (Fig. 2). This operation decreased the peak oxygen supply and the corresponding peak power requirements. It also decreased the SVI during the pilot-plant study, but was not evaluated here. The required aeration power increased with increase in θ_c, as can be expected (refer to Table 4).

TABLE 5 (1994)
Feasibility on running expenses, income and savings per year

Working expenses	- R 646 000
Income (protein sales)	+R 965 000
Net income	+R 319 000
Effluent tariff savings	+ R3 780 000
Annual income and savings	+ R4 099 000
1 US$ ~ SAR 3.60	

Biomass characteristics and protein production. Results are summarised in Table 4. The SVI values were higher than expected (less than 80 mℓ/g for the pilot plant), but did not impair settling. The higher values may be due to the longer anoxic period applied (Lakay et al., 1999). FOC varied between 1 (few) and 2 (some). Granules of c. 0.5 mm diameter were noticed (Beun et al., 1999; Dangcong et al., 1999).

The shorter θ_c increased the biomass production, as expected. Biomass production was, however, approximately double compared to the pilot-plant results, which is difficult to explain. The CP is slightly higher and did not increase with longer θ_c. The θ_c can, however, not be used as a variable in this case due to a combined primary and secondary sludge. An even shorter θ_c seems attractive for increasing feasibility by increasing protein production and decreasing aeration cost, but could not be evaluated due to a limiting sludge-handling capacity. The combined sludge contained 8% crude fibre (AOAC, 1984) by dry mass which originated from the TSS in the substrate.

The biomass was gravity thickened to c. 20 g/ℓ, mixed with primary sludge and a polymer and dewatered. The dewatered dry solids concentration was c. 30%.

Economic feasibility. A financial feasibility study was completed showing that all expenses were recovered within the first year of operation through protein sales and effluent tariff savings. The feasibility was based on 250 slaughter days per year and 2 000 cattle units per day. The results for the running concern are given in Table 5. A net income was generated from protein sales but the main financial benefit was the saving in effluent tariffs due to pretreatment of the effluent. The feasibility study, however, assumes the existence of a by-products plant for product handling, and that the produced protein is used as a supplement to carcass meal which is the main protein source.

Conclusions

The modified SBR process was successfully implemented from pilot to full scale. Some of the results did however differ, giving a warning for careful consideration to relatively small differences.

The modified SBR process was easy to operate and adapted readily to changes in raw effluent generation. Self-regulating and stable operation was ensured and successful pretreatment achieved. The process is ideal for treatment of effluent generated batch wise and with a variable volume. Special attention should, however, be given to floatable material that is easily confined and concentrated in the reactor.

Biomass with a relatively good settleability was produced and could be used as a supplement to carcass meal for animal feed. Protein production and feasibility can probably be increased by decreasing the θ_c to less than 5 d.

The process proved to be feasible with a net income (on running cost) from protein sales on the condition of an existing by-products plant, and protein addition to another main protein source. It is also clear that the main financial benefit is the saving in effluent tariffs due to pretreatment of the effluent.

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