Anaerobic processing of slaughterhouse wastewater in a SBR.

Le traitement des eaux usées d'abattoir par digestion anaérobie dans un bioréacteur à opérations séquentielles.

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Abstract

Abattoir effluents reaching rivers and streams may contribute significant levels of biological oxygen demand (BOD) and other nutrients, resulting in riverbed and stream pollution. At the present time, there is no economical, stable, efficient, easy-to-use and operate process to stabilize, deodorize, or recover usable energy from slaughterhouse wastewater. The Agriculture and Agri-Food Canada Research Center is currently evaluating the feasibility of using anaerobic digestion in sequencing batch reactors to treat slaughterhouse effluents. Experiments were conducted in four, 42 L bioreactors operated at 30°C. Preliminary results indicate that this process is very effective in reducing odours and the pollution potential of slaughterhouse wastewater. The process removed up to 98% and 91% of the total COD and suspended solids respectively. It also yielded a large quantity of high quality biogas (0.54-0.67L / g of VS fed) with a methane content of 70 to 75%. The proposed process is very stable and easy-to-operate.

Résumé

Dans certaines régions, la gestion actuelle des eaux usées d'abattoirs cause de sérieux préjudices à l'environnement. Ces eaux usées sont principalement composées d'un mélange complexe de matières grasses, de protéines et de fibres. Elles contiennent une concentration suffisante : a) de matière organiques pour appauvrir la teneur en oxygène des eaux de surfaces, b) de nutriments pour stimuler la prolifération des algues. Donc le rejet des eaux usées d'abattoir dans les cours d'eau a des conséquences néfastes sur la flore et la faune aquatiques. De plus, le public augmente les pressions auprès des gouvernements locaux et provinciaux afin que l'industrie des viandes adopte une gestion plus écologique de ses effluents. Le rejet libre des eaux usées dans l'environnement n'est plus une solution acceptable. Actuellement, il y a un besoin urgent pour une biotechnologie environnementale économique, simple à utiliser, stable, performante et facilement intégrable dans les abattoirs.

Agriculture et Agro-alimentaire Canada réalise actuellement une étude de faisabilité concernant l'utilisation des bioréacteurs anaérobies à opérations séquentielles pour le traitement des eaux usées d'abattoir. Les expériences ont été effectuées dans quatre (4) bioréacteurs anaérobies de 42 l, à opérations séquentielles. La température d'opération et le taux de chargement organique étaient de 30°C et 5.75 g DCO $L^{-1}d^{-1}$ respectivement. Le procédé a réduit la demande chimique en oxygène (DCO) totale de 91%, et a éliminé jusqu'à 85% des matières volatiles solides. Un biogaz de haute qualité, contenant 70 à 75% de méthane, a été produit (0.56 - 0.64 l CH_4/g MVS alimenté). De plus, cette technologie qui est très stable et simple d'utilisation, désodorise complètement les eaux usées.

1. Introduction

Slaughterhouse wastewater has a complex composition and is very harmful to the environment (Polprasert et al., 1992). It is strong compared to domestic wastewater. After the initial screening of coarse solids, slaughterhouse wastewater is mainly composed of diluted blood, fat, and suspended solids. It may also contain some manure.

In Québec and Ontario, most slaughterhouses send their wastewater to a municipal treatment plant. However, in order to minimise surcharge costs exacted by municipalities, larger slaughterhouses usually apply some type of primary and/or chemical pre-treatment to the wastewater. These include the screening of coarse solids, air flotation tank for fat recovery and the addition of chemicals for fat and protein reduction, etc. These treatments, however, are somewhat costly and are not sufficient to totally eliminate surcharge costs which are bound to increase in the more populated areas.

At the present time there is no economical, stable, easy-to-use and operate process to stabilize, deodorize, or recover usable energy from slaughterhouse wastewater in Canada. Anaerobic processes that were experimented in the past concentrated mainly on energy production and less consideration was given to pollution potential reduction. However, anaerobic digestion in a Sequencing Batch Reactor (SBR), as developed by Agriculture Canada, could be an interesting alternative for an efficient and economical treatment (or pre-treatment) of slaughterhouse wastewater. This new technology, which had been successfully applied in the laboratory to the treatment of swine manure slurry, can operate with limited capital costs, energy and manpower.

The objectives of this study were to characterize wastewater form slaughterhouses in eastern Canada, and to determine the feasibility of using anaerobic digestion in an ASBR to treat slaughterhouse wastewater at a temperature of 30 C. In this study, the process stability will be considered as the most important criterion for the evaluation of the technology. The slaughterhouse industry needs a process that is very stable and not affected by variations in wastewater temperature and strength.

2. Literature review

The nature and composition of slaughterhouse wastewater have been discussed in detail by Hammer and Jacobson (1970) and Issac and Anderson (1974). The major characteristics are: 1) high organic strength; 2) sufficient organic biological nutrients; 3) adequate alkalinity; 4) relatively high temperature (20 to 30 C); and 5) free of toxic material. Metzner and Temper (1990) indicated that slaughterhouse wastewaters with the above characteristics are well suited to anaerobic treatment. Full scale anaerobic lagoon systems have been used to treat slaughterhouse wastewater, (Enders et al. 1968; Wymore and White 1968). The efficiency of these lagoons in reducing the BOD5 ranged between 60 and 90%. Suspended solids removal was not reported. These anaerobic lagoons were not covered. The only natural protection against exposure of anaerobic bacteria to air was provided by a layer of grease that floated on the liquid surface. The biogas produced, including methane escaped directly to the atmosphere. Release of methane to the atmosphere is not an acceptable practice anymore. Methane has a high heat trapping capacity and is a major component of greenhouse gas. A large floating cover could be used to collect the biogas at the surface of the lagoon. Such a system would work well in the absence of cold weather. Here in Canada, the construction of a lagoon cover with enough durability and strength to resist large unbalanced forces due to ice and snow accumulation would be very costly. Also, the temperature in the lagoon would be very low during the winter. As a result, the anaerobic lagoon system would not adequately process the wastewater. Also if a process failed in a large lagoon, it would not be possible to restart it.

To accelerate the treatment and to reduce area requirements, more sophisticated anaerobic systems involving digesters (as opposed to lagoons) have been used to treat slaughterhouse wastewater. Sayed et al. (1987; 1988) used upflow anaerobic sludge blanket reactors to treat the wastewater. Metzner and Temper (1990) and Tritt (1992) used fixed-bed reactors for the anaerobic digestion of slaughterhouse wastewater. These reactors were very effective in removing the soluble organic (efficiency > 90%) but their efficiency in removing the suspended solids was very low 31 to 60%. The low efficiency in removing the suspended solids was due to the hydraulic conditions inside these reactors. Suspended solids were maintained in suspension by the continuous influent flow, and were therefore present in the digester effluent. With this system, a secondary clarifier to settle the suspended solids and a recirculation system to return the suspended solids to the reactor are required. The addition of these equipments substantially increased the capital cost and the operation complexity of the process. Its operation required a skilled technician.

An anaerobic process would be attractive to the slaughterhouse industry if a low cost, simple, efficient and easy-to-operate process was available. The sequencing batch reactors has the potential to be a low cost as well as an efficient system to remove both soluble COD and suspended solids. SBR indicates that the process occurs in a tank in the sequence given in Figure 1: fill; react; settle; draw and idle. During the fill period the wastewater is added to the tank. During the react period the alimentation is stopped. During both the feed and react periods the soluble COD and some of the organic particulate are removed biologically by microorganisms action. During the settling period, no mixing is provided. This provides quiescent conditions (optimum conditions) for the separation of treated wastewater and suspended solids. Dague et al. (1992) stated that in an anaerobic sequencing batch reactors the Food/Microorganisms ratio is high after the filling period and low just prior to the settling period. They also indicated that the above operating conditions result in efficient bioflocculation and solids separation. Dague et al. (1992) also stated that with a SBR the partial pressure of C02 above the liquid zone is maintained in the reactor during the settling period. As a result no significant quantity of C02 is transferred to the head space during the settling period. The abscence of mixing and CO_2 transfer results in quiescent settling conditions for the suspended solids. This operation retains a very high concentration of microorganisms in the digester. Previous systems used secondary clarifier and degasification equipment to recover the anaerobic bacteria. But because the secondary clarifier never provided quiescent conditions, bacteria were still washed out of the system. In several cases, this led to process failure.

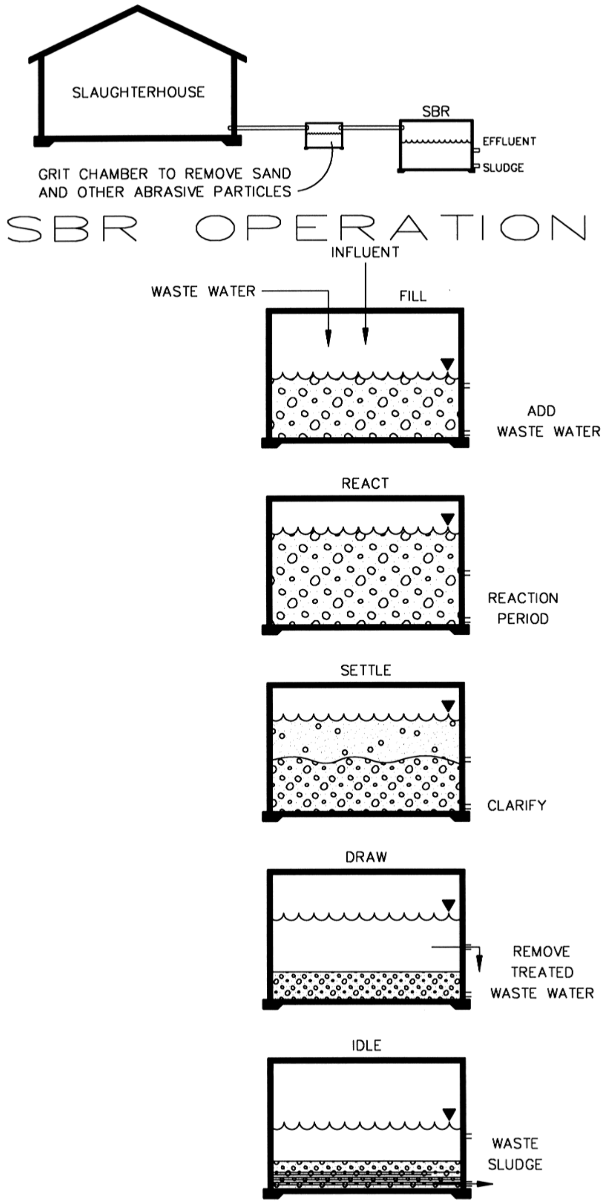


Figure 1
Operation of the ASBR process.

3. Analysis of wastewater from different slaughterhouses

Wastewater samples were collected at various locations in the wastewater treatment area of six slaughterhouses. Table 1 presents the composition of the raw wastewater, prior to any treatment except for the screening or settling of coarse solids. Screens and primary settling tanks are usually situated at the inlet of the wastewater treatment area and it is often difficult to sample before that point. Table 1 shows that the strength of raw wastewater varies among slaughterhouses but variation seems to be independent of plant capacity: smaller slaughterhouses do not produce stronger or weaker wastewater. Total COD, suspended solid (SS), total nitrogen (TKN), and total phosphorus (P) concentrations of the raw wastewater collected at the six slaughterhouses are 2 to 9 times higher than those of a strong domestic wastewater which has a total COD of 1000 mg/L, a SS content of 350 mg/L, and TKN and P concentrations of 85 and 15 mg/L, respectively (Metcalf & Eddy, 1991).

Parameters (mg/l)	1	2	3	4	5	6
COD total	2941	3589	4976	2333	9368	3417
COD soluble	1510	2605	2817	778	4551	1250
Total solids	2244	2727	3862	2747	6037	2481
Volatile solids	1722	1966	3153	1204	4745	1846
Suspended solids	957	736	1348	877	2397	1431
Volatile suspended solids	770	576	1192	594	2182	1149
Total Kjeldahl nitrogen	174	271	372	90	629	158
Ammonia	41	154	99	19	185	20
Protein	133	117	272	71	444	137
Total phosphorous	20	-	-	28	61	80
pH	6.7	7.2	6.5	4.9	7.0	6.5
$CaCO_3$	333	333	333	83	1014	250

Table 1
Analysis of raw wastewater from six slaughterhouses prior to any treatment except the screening or settling of coarser solids.

Wastewater samples were always collected in the morning or early afternoon and did not include water from the afternoon washing or from emptying the hot water tank used to wash the animals during the day. The raw wastewater collected was thus probably stronger than a 24 hour-composite sample which would include wash water. Table 2 presents the range of values as well as the coefficients of variation for the different parameters tested in the raw wastewater samples from slaughterhouse. For most parameters, overall variation was less than 20%. However, the highest total and soluble COD contents (11 530 and 5490 mg/L, respectively) were 60 to 65% higher than the lowest values (6908 and 3449 mg/L). Total and soluble COD contents are important parameters when designing a wastewater treatment system. Therefore a system to treat slaughterhouse wastewater would have to be able to sustain these variations in influent COD.

Parameters	Range (mg/l)	Coefficient of variation (%)
COD total	6908 - 11530	16
COD soluble	3449 - 5490	19

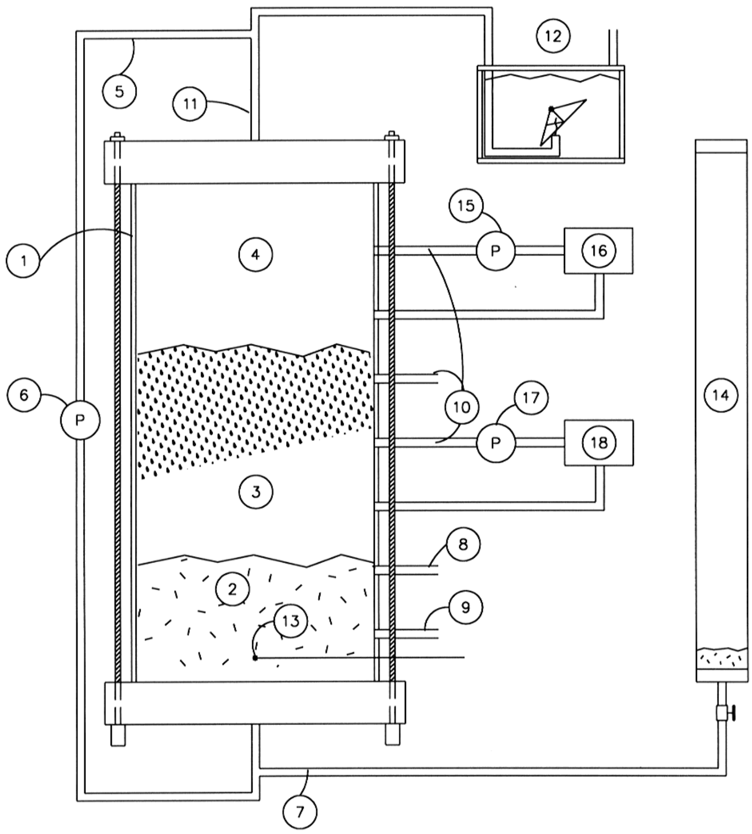
Total solids	4892 - 7121	16
Volatile solids	3647 - 5724	23
Suspended solids	2135 - 2700	10
Volatile suspended solids	1936 - 2427	10
Total Kjeldahl nitrogen	534 - 735	12
Ammonia	89 - 246	36
Protein	288 - 530	22
pH	7.0 - 7.1	0
$CaCO_3$	917 - 1056	6

Table 2
Variation in raw wastewater quality at Slaughterhouse 5
during four sampling over a six-month period.

4. Evaluation of anaerobic digestion in a SBR

Materials and Methods

Figure 2 is a schematic diagram of the bench scale SBRs used in this study. Four 42 L plexiglass digesters were located in a controlled temperature room. The SBRs were mixed by recirculating the biogas. Wet cup gas meters were used to measure the daily biogas production. The feed samples were stored in a freezer at -15 C to prevent biological activity. They were heated to the digester operating design temperature (30 C) prior to feeding.



1 300 mm DIAMETER PLEXIGLASS DIGESTER
2 SLUDGE BED ZONE
3 VARIABLE VOLUME ZONE
4 HEAD SPACE ZONE
5 GAS RECIRCULATION LINE
6 BIOGAS RECIRCULATION PUMP
7 INFLUENT LINE
8 EFFLUENT LINE
9 SLUDGE SAMPLING PORT, ALSO USE FOR SLUDGE WASTAGE
10 MIXED LIQUOR OR SUPERNATENT SAMPLING PORT
11 GAS OUTLET
12 GAS METER
13 THERMOCOUPLE
14 FEEDER TUBE
15 GAS PUMP
16 HYDROGEN GAS MONITOR
17 LIQUID PUMP
18 DISSOLVED HYDROGEN GAS MONITOR

Figure 2
Schematic of laboratory scale SBRS

Operating Conditions

For startup run, the effects of inoculum type on process start-up was investigated. Fill and react period lengths were kept constant and intermittent mixing was provided (1 minute every 5 minutes) to the SBRs. Operating conditions for the start-up run are given in Table 3. Digesters 1 and 2 were initially started using 13 L of anaerobic granular sludge obtained from the anaerobic wastewater treatment plant of Agropur Co-Operative dairy plant at Notre-Dame du Bon Conseil, Quebec. Digesters 3 and 4 received 13 L of anaerobic non-granulated sludge obtained from the Robert O. Pickard Environmental Centre, Ottawa, Ontario. The Agropur sludge substrate consisted mainly of fats and proteins. The anaerobic municipal sludge substrate comes from both primary and secondary clarifiers. Composition of the Agropur and municipal anaerobic sludge are given in Table 4.

Digester No	Feeding frequency (# / week)	Fill period (hr)	React period (hr)	Sludge Type
1-2	3.5	1	41	A
3-4	3.5	1	41	B

A - Agropur sludge. B - Municipal sludge.

Table 3
SBR Operating conditions

CONSTITUENT	AGROPUR SLUDGE	MUNICIPAL SLUDGE
Total solids %	7.5	4.9
Total suspended solids %	7.3	4.8
Volatile solids %	3.2	2.8
Volatile suspended solids %	3.2	2.7
Soluble COD g/l	0.7	0.7
Total COD g/l	89.7	62.5

Table 4
Inocula characteristiques

Monitoring and Sampling

Biogas production was monitored daily and the biogas composition weekly. The feed, digester mixed liquor and effluent were analysed for soluble and total COD, solids contents (TS, VS, fixed solids, TSS, fixed suspended solids), ammonia and total nitrogen, VA concentration, pH and alkalinity. The analytical procedures used to determine the above parameters were carried out according to standard methods (APHA, 1989). Gas composition and VA concentrations were determined by gas chromatography.

5. Result and discussion

The startup period was divided into three runs corresponding to three different feed stocks from the slaughterhouse (Table 5). The ASBRs were fed every two days. The loading rate was slowly increased from 1.1 g COD per litre of digester mixed liquor at the beginning of run 1 to 11.5 g COD/L at the end of run 3. Table 5 gives average concentrations of total and soluble COD, solids and nutrients in the raw wastewater fed to the ASBRs and in the effluents from the ASBRs for the three runs. It also gives the level of removal of these compounds.

Run n°	Parameters	Influent (mg/l)	Effluent		% Removal	
			Agropur sludge (mg/l)	Municipal sludge (mg/l)	Agropur sludge A	Municipal sludge B
1	Total COD	6908	1511	1450	78	79
	Soluble COD	3449	495	512	86	85
	Total solids	4892	2959	2091	40	57
	Volatile solids	3647	1002	987	73	73
	Suspended solids	-	1411	787	-	-
	Volatile sus.solids	-	764	3775	-	-
	Total nitrogen	534	510	741	4	-
	Ammonia	246	444	664	-81	-170
	Protein	288	66	78	77	73
	Methane (L/g of VS fed)	-	0.64	0.67	-	-
2	Total COD	9665	1842	880	81	91
	Soluble COD	4714	159	104	97	98
	Total solids	6098	3381	1742	45	71
	Volatile solids	4864	1406	573	71	88
	Suspended solids	2135	2519	810	-18	62
	Volatile sus. solids	1936	1246	490	36	75
	Total nitrogen	619	621	571	0	8
	Ammonia	89	525	498	-489	-458
	Protein	530	95	73	82	86
	Methane (L/g of VS fed)	-	0.55	0.58	-	-
3	Total COD	11530	601	365	95	97
	Soluble COD	9665	1842	880	81	91
	Total solids	7121	1630	1457	77	80
	Volatile solids	5724	425	303	93	95
	Suspended solids	2658	347	233	87	91
	Volatile sus. solids	2427	238	135	90	94
	Total nitrogen	735	645	552	12	25
	Ammonia	221	612	536	-177	-143
	Protein	514	33	16	94	97
	Methane (L/g of VS fed)	-	0.56	0.54	-	-

Table 5
Quality of wastewater before and after anaerobic treatment in SBRS

High COD removal was achieved in all the experimental runs, especially in the last run of the startup period when total COD was reduced to 601 and 365 mg/L (95% and 97% removal) by sludge A and B, respectively. VS removal ranged from 73%

in run 1 to 95% in run 3. The reduction in soluble COD was due to microbial activity while total COD and VS removal were due to both microbial activity and solids settling. Both types of anaerobic sludge had excellent settling characteristics even though the quiescent conditions were sometimes disturbed by biogas production during the settling period. In this experiment, TSS concentration in the effluent from run 3 was as low as 347 and 233 mg/L for sludge A and B, respectively. It corresponded to over 87% and 91% removal, respectively, and was well below the TSS maximum allowed by municipalities. Total Kjeldahl nitrogen concentration remained high in the effluent but the organic nitrogen was mostly converted to ammonium during the process. Ammonia-nitrogen represented 20 to 50% of the influent TKN but accounted for over 90% of the TKN in the ASBR effluent.

The ASBRs produced a high quality biogas which contained approximately 74% methane and 25% CO_2. Methane production varied between 0.54 and 0.67 L/g VS fed. There was no acetic, propionic or butyric acids accumulation in the bioreactors, indicating that the technology is very stable. The effluent had an average pH of 7.6, which was slightly higher than that of the influent. Alkalinity was increased from approximately 900 mg/L as $CaCO_3$ in the influent to about 2500 mg/L in the effluent. The increase in alkalinity will improve the buffering capacity of the wastewater and is thus beneficial. The effluent was almost odourless when compared to the raw slaughterhouse wastewater. Also, the dark red colour of the raw wastewater completely disappeared and the treated wastewater had a pale yellowish colour.

The anaerobic sludge had excellent settling characteristics. When mixing was stopped at the end of the react period, a settling zone or liquid/solids interface was forming and the sludge blanket completely settled at the bottom of the SBR. Another very important feature of ASBR process is that it does not require continuous feeding. Therefore, in slaughterhouse applications it should be loaded during the day and react at night. Therefore the SBR will make use of existing wastewater handling equipment at the plant.

6. Conclusion

Preliminary data of anaerobic digestion at 30 C in a SBR showed that the proposed technology has good potential to substantially reduced the pollution load of slaughterhouse wastewater. The digester effluents were almost odourless when compared to the raw slaughterhouse wastewater. Also, the SBR was efficient in retaining the biomass. It provided good solids-liquid separation. The proposed process show good potential to provide the slaughterhouse industry with a more environmentally sound wastewater management alternative. It will eliminate the need for expensive air flotation and sedimentation processes currently used at some slaughterhouses. It will also substantially reduce the high treatment cost at plants where the wastewater is discharged to the municipal wastewater system. Finally the above process will recover a significant quantity of energy (methane) that could be used to heat or produce hot water at the slaughterhouse plant.

7. Acknowledgement

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