

Characterization of wastewater from hog slaughterhouses in Eastern Canada and evaluation of their in-plant wastewater treatment systems

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Massé, D.I. and Masse, L. 2000. **Characterization of wastewater from hog slaughterhouses in Eastern Canada and evaluation of their in-plant wastewater treatment systems.** *Can. Agric. Eng.* 42:139-146. Literature on existing systems for slaughterhouse wastewater treatment was reviewed and discussed in terms of technology usefulness and relevance under Canadian conditions. The wastewater from six hog slaughterhouses in Québec and Ontario was also characterised before and after treatment at the plant. In raw wastewater, total chemical oxygen demand (TCOD) ranged from 2333 to 8627 mg/L and suspended solids (SS) varied between 736 and 2099 mg/L. Slaughterhouse wastewater composition in terms of organic strength, inorganic elements, alkalinity, and pH is adequate for biological treatment. Two slaughterhouses only settled their wastewater before discharging it to the municipal sewer. Three plants used primary treatment to precipitate blood and remove floating fat, while one further treated its wastewater using an aerobic trickling filter. Although preliminary treatment at the slaughterhouse reduced the level of pollutants, TCOD and SS concentrations were still too high for sewer discharge without being imposed a municipal surcharge. In addition, all treatments produced large amounts of putrefactive and bulky sludge, which required special handling and/or further treatment.

Cet article présente d'abord une recension des écrits sur les systèmes de traitement des eaux usées d'abattoir. Les technologies d'épuration sont décrites en fonction de leur utilité dans le contexte canadien. Les eaux usées provenant de six abattoirs de porcs au Québec et en Ontario ont ensuite été caractérisées avant et après le traitement effectué aux abattoirs. Dans les eaux usées brutes, la demande chimique en oxygène totale (DCOT) varie de 2 333 à 8 627 mg/l, et les matières en suspension (MES), de 736 à 2 099 mg/l. Les eaux usées d'abattoir contiennent une charge organique, des concentrations d'azote, de phosphore et d'oligo-éléments, une alcalinité et un pH adéquats pour un traitement biologique. Deux des abattoirs visités se contentent de transvider les eaux usées dans des bassins de décantation avant de les déverser dans le réseau municipal d'égouts. Trois abattoirs effectuent une épuration primaire dans le but de précipiter le sang et de favoriser la flottaison des gras, tandis qu'un abattoir traite aussi ses eaux usées à l'aide d'un filtre bactérien aérobie. Les traitements d'épuration utilisés dans les abattoirs réduisent le niveau des matières polluantes mais se révèlent insuffisants pour ramener la DCOT et les MES à des concentrations permettant aux établissements de déverser leurs eaux dans les égouts municipaux sans se voir imposer une surtaxe. En outre, tous les traitements recensés produisent une quantité considérable de boues putrides et volumineuses qui nécessitent une manutention spéciale ou des traitements ultérieurs.

INTRODUCTION

Slaughterhouse wastewater is very harmful to the environment. Effluent discharge from slaughterhouses has caused the deoxygenation of rivers (Quinn and Farlane 1989) and the contamination of groundwater (Sangodoyin and Agbawhe 1992). The pollution potential of meat-processing and slaughterhouse plants has been estimated at over 1 million population equivalent in the Netherlands (Sayed 1987), and 3 million in France (Festino and Aubart 1986). Blood, one of the major dissolved pollutants in slaughterhouse wastewater, has a chemical oxygen demand (COD) of 375 000 mg/L (Tritt and Schuchardt 1992). Slaughterhouse wastewater also contains high concentrations of suspended solids (SS), including pieces of fat, grease, hair, feathers, flesh, manure, grit, and undigested feed (Bull et al. 1982). These insoluble and slowly biodegradable SS represented 50% of the pollution charge in screened (1 mm) slaughterhouse wastewater, while another 25% originated from colloidal solids (Sayed et al. 1988).

Slaughterhouse wastewater quality depends on a number of factors, namely:

1. Blood capture: the efficiency in blood retention during animal bleeding is considered to be the most important measure for reducing biological oxygen demand (BOD) (Tritt and Schuchardt 1992);
2. Water usage: water economy usually translates into increased pollutant concentration, although total BOD mass will remain constant;
3. Type of animal slaughtered: BOD is higher in wastewater from beef than hog slaughterhouses (Tritt and Schuchardt 1992);
4. Amount of rendering or meat processing activities: plants that only slaughter animals produce a stronger wastewater than those also involve in rendering or meat processing activities (Johns 1995).

Most slaughterhouse wastewater quality data have been generated in Europe (Bull et al. 1982; Sachon 1982, 1986; Sayed 1987; Tritt and Schuchardt 1992), Australia (Johns 1995) and the USA (Camin 1970) and little information exists on quality and treatment of slaughterhouse wastewater in Canada. The objective of this project was thus to characterise wastewater

from hog slaughterhouses in Québec and Ontario. In 1995 and 1996, six hog slaughterhouses were visited. Data on wastewater treatment and wastewater quality before and after in-plant treatment are presented. Literature on existing technologies for slaughterhouse wastewater treatment will first be briefly reviewed and discussed in terms of the usefulness and relevance of these technologies to Canadian conditions.

SLAUGHTERHOUSE WASTEWATER TREATMENT: A REVIEW

Sewer discharge

Sewer discharge of wastewater without preliminary treatment is mostly used by smaller slaughterhouses located close to municipal treatment plants. Domestic wastewater, generally much lower in BOD and inorganic nutrient concentration, dilutes the slaughterhouse wastewater and makes it more amenable to biological treatment. The main disadvantage of sewer discharge is the surcharge imposed by municipalities to treat the wastewater. In addition, few municipal treatment plants will accept large quantities of untreated slaughterhouse wastewater.

Land application

Land application of slaughterhouse wastewater by spray irrigation has been mainly used in the USA (Bull et al. 1982). The advantages of the system are its simplicity and low cost. The disadvantages include possible surface and ground water contamination, odour problems, greenhouse gas emission, and soil pore clogging from excessive fat loads. Application on constructed wetlands could also be used as a polishing treatment for biologically treated wastewater (John 1995). Land application, however, is not practical in subfreezing temperatures, and in most parts of Canada large volumes of wastewater would have to be stored during the winter months.

Physico-chemical treatments

Grit chambers, screens, settling tanks, and dissolved air flotation (DAF) units are widely used for the removal of SS, colloids, and fats from slaughterhouse wastewater. In DAF units, air bubbles injected at the bottom of the tank transport light solids and hydrophobic material, such as fat and grease, to the surface where scum is periodically skimmed off. Camin (1970) surveyed wastewater treatment in over 200 meat packing plants in the USA and concluded that, compared to aerobic and anaerobic systems, air flotation was the least efficient treatment in terms of dollars per weight of BOD removed.

Blood coagulants (e.g. aluminium sulphate and ferric chloride) and/or flocculents (e.g. polymers) are sometimes added to the wastewater in the DAF unit to increase protein flocculation and precipitation as well as fat flotation. Chemical-DAF units can achieve COD reduction ranging from 32 to 90%, and are capable of removing large amounts of nutrients (Johns 1995). However, operational problems have been reported, and the system produces large volumes of putrefactive and bulky sludge that requires special handling and further treatment (Johns 1995).

Aerobic treatment

In aerobic digestion, microorganisms degrade organics in the presence of oxygen. Bélanger et al. (1986) described the operation of a 1000 m³ aerobic lagoon treating slaughterhouse

wastewater in southwestern Québec. Twenty-four submerged emitters transferred 850 litres of oxygen per minute. Influent BOD₅ ranged from 1500 to 3000 mg/L and hydraulic retention time (HRT) averaged 11 days. Effluent BOD₅ concentration was generally below 50 mg/L, except in winter when it reached 645 mg/L and remained high for almost two months due to cold conditions in the lagoon. The system required daily maintenance by a trained technician and daily drainage of accumulated sludge. One disadvantage of aerobic systems is the generation of large quantities of biological sludge that must be treated before disposal.

Besides lagoons, extended aeration systems and trickling filters have been the most popular aerobic processes for the treatment of meat packing and slaughterhouse wastewater (Bull et al. 1982). High BOD removals are reported but effluent SS concentrations are often elevated due to poor sludge settleability (Johns 1995). In addition, oxygen requirements and treatment time increase steeply with wastewater strength. For this reason, aerobic digestion is considered less economical than anaerobic treatment for wastewaters with COD concentrations above 4000 mg/L, and with the development of high-rate anaerobic reactors the cut-off level may be lower than 4000 mg/L (Rudd 1985). Aerobic systems, however, could be used for final purification and nutrient removal, following physico-chemical or anaerobic treatment, wherever slaughterhouses must treat their wastewater to river discharge standards.

Anaerobic treatment

During anaerobic digestion, organics are degraded by a diversity of bacteria into methane in the absence of oxygen. Anaerobic systems are not used in Canada but they represent an interesting alternative for treatment at the plant. Their advantages are:

1. a high efficiency in reducing COD in soluble and insoluble form;
2. a low sludge production of only 5% to 20% of that generated by aerobic systems (Speece 1996);
3. the recovery of usable energy in the form of methane;
4. no aeration energy requirement;
5. no chemical handling;
6. the biomass can remain unfed for long periods without deteriorating.

Anaerobic treatment can be divided into two main categories, low-rate (lagoons) and high-rate systems.

Anaerobic lagoons Anaerobic lagoons have been one of the most extensively used systems for treating slaughterhouse wastewater in the USA and Australia, where climatic conditions and land availability permit the construction of large lagoons (Johns 1995; Rollag and Dornbuh 1966). Low capital, operational, and maintenance costs combined with a high efficiency in reducing polluting charges have all contributed to the popularity of lagoons. The disadvantages of lagoons include the large area requirement, odor problems, and the emission of methane, one of the major contributors to greenhouse gas, with a heat-trapping capacity 20 to 30 times that of carbon dioxide.

Odor and gas emissions can be contained by covering lagoons. Dague et al. (1990) described the operation of a large covered anaerobic lagoon treating hog slaughterhouse wastewater. Influent BOD₅ ranged from 1600 to 4800 mg/L and the HRT was 13 days. Reduction in BOD₅ and SS averaged 87% and 81%, respectively. A methane production of 0.51 m³

per kg of BOD₅ removed was obtained. However, covered lagoons require high BOD loading to generate economic quantities of biogas (Safley and Westerman 1988, 1992). In Canada, the construction of a lagoon cover with enough durability and strength to resist large unbalanced forces due to wind, ice, and snow accumulation would be very costly. In addition, liquid temperature would be excessively low in winter. In southwestern Québec, the average temperature of an aerobic lagoon varied between 0 and 8.5°C during the winter months (Bélanger et al. 1986). The efficiency of anaerobic lagoons is greatly reduced below 21°C (Hammer and Jacobson 1970). In addition, anaerobic bacteria are sensitive to rapid changes in temperature, and it would be almost impossible to restart a large anaerobic lagoon if it failed during a cold period.

High-rate anaerobic reactor More sophisticated anaerobic systems were developed to accelerate treatment and reduce area requirement, especially in places where land is expensive and scarce, such as Europe and Asia. Area requirement is also an important factor in cold climatic conditions where wastewater treatment has to be applied indoors. The first high-rate anaerobic design, the anaerobic contact reactor (ACR), basically consisted of a stirred tank reactor followed by a sludge separator. The first report of a full-scale ACR treating slaughterhouse wastewater was from the United Kingdom (Black et al. 1974). The reactor was operated at 32.5°C and received pre-settled wastewater at organic loading rates (OLRs) ranging from 0.12 to 0.28 kg m⁻³d⁻¹. Reduction in BOD₅ was approximately 90%. However, because of technical problems with the clarifiers, the effluent contained high concentrations of biomass, and volatile solids reduction ranged between 41 and 67%. A mesophilic ACR (30 to 35°C) was also built in a meat packing plant in the USA (Kostyshyn et al. 1988). Wastewater was first pre-treated in a DAF unit and average COD and SS concentrations in influent were 6320 and 2342 mg/L, respectively. During the first six months of operation, COD and SS reduction averaged 85 and 75%, respectively, at OLRs between 2 and 3 kg m⁻³d⁻¹ and HRTs between 1.7 and 2.5 days. However, the plant operator reported malfunctioning of the clarifiers (Personal communication: Packerland Packing Co. 1996). Poor biomass settleability appears to be a recurrent problem with ACRs.

Most modern high-rate anaerobic reactors have built-in devices to retain bacteria. In anaerobic filter reactors (AFRs), retention is achieved through biomass adhesion to a fixed or floating inert material called filter. Anaerobic filter reactors are generally robust and resistant to shock loads, but carrier material is expensive and some designs require intense supervision (Defour et al. 1986). Filter material can also become clogged by high concentrations of undissolved organics. Campos et al. (1986) described the operation of an industrial anaerobic filter reactor (AFR) treating meat-processing wastewater at 25°C over a 6-year period. At an OLR of 1.4 kg m⁻³d⁻¹, COD reduction was 76 and 85% at an HRT of 13 and 24 h, respectively. Influent SS concentration (889 mg/L) was reduced by 88%. A full-scale AFR was also constructed in a German rendering plant (Metzner et al. 1990). Primary treatment included a grease separator, a mud-trap, and a 0.6-mm drum screen. The AFR was operated at 36°C at OLRs between 3 and 10 kg m⁻³d⁻¹ and HRTs between 21 and 27 h. Reduction in COD ranged from 70 to 90%.

In upflow anaerobic sludge blanket (UASB) reactors, influent enters at the bottom of the digester, flows across a compact layer of bacteria (the sludge blanket) and exits at the top of the reactor. Successful operation depends on the formation of bacterial flocs or granules that accumulate and easily settle at the bottom of the digester. Reactor operation requires close supervision. Liquid velocity must be low enough to prevent excessive lifting of the sludge blanket and equalisation tanks must be used to prevent strong variations in organic loading (Defour et al. 1994). Full-scale UASB reactors for slaughterhouse wastewater treatment were installed in the Netherlands, Belgium, and New Zealand, but operating data are unavailable except that in the Netherlands, granules could not be obtained, and the UASB had to be operated as a flocculent system (Johns 1995). The UASB can operate with flocculent sludge, although granules tend to settle better and thus allow increased flow rate.

The anaerobic sequencing batch reactor (ASBR), as developed by Agriculture and Agri-Food Canada, could represent an economical, stable, efficient, easy-to-use, and easy-to-operate process to treat and recover usable energy from slaughterhouse wastewater. This new technology, which has been successfully applied at laboratory and semi-commercial scales for the treatment of swine manure slurry, can operate with limited capital costs, energy, and manpower (Massé 1995; Massé and Croteau 1998; Massé and Droste 1997; Massé et al. 1996, 1997). It has only been tested on a laboratory-scale for the treatment of slaughterhouse wastewater but preliminary results are encouraging (Massé and Masse 2000).

MATERIALS and METHODS

Between June 1995 and January 1996, three Québec and three Ontario slaughterhouses dealing exclusively in pork meat were visited. The slaughterhouses varied in size and included small family plants as well as large corporations. In this paper, the slaughterhouses are referred to by a number from 1 to 6. Slaughterhouse 1 had the lowest capacity, while Slaughterhouse 6 had the largest (Table I). Three of the plants only dealt in slaughtering, while the other three were also involved in some rendering or meat processing activities. Their wastewater treatment systems were examined and information was collected on plant capacity, waste disposal, water usage, and treatment system operation and cost. Wastewater volume per animal killed was estimated by dividing wastewater production, as evaluated by the slaughterhouse, by the average number of animals killed during the same period.

At all slaughterhouses, samples were collected in the morning or early afternoon. The untreated (raw) wastewater was sampled after the screening or settling of coarser solids. Screens and primary settling tanks are usually located at the inlet of wastewater treatment areas, and it is difficult to sample before that point. Raw wastewater samples did not include washwater or wastewater from the scalding tank. At Slaughterhouses 1 and 2, one sample was collected from the holding tank, where the wastewater is sent before being discharge to the municipal sewer. At Slaughterhouses 4 and 6, one sample was collected from the settling tank and one at the outlet of the DAF unit. At Slaughterhouse 3, one sample was collected at each of four places in the treatment room: (1) after the 1-mm screen, (2) at the outlet of the DAF unit, (3) at the outlet of the aerobic trickling filter, and (4) at the final discharge pipe. At

Table I. Capacity, water usage, and wastewater treatment at six pork slaughterhouses (1995-1996).

Slaughter house	Capacity (head/wk)	Wastewater production (m ³ /d)	In-plant wastewater treatment	Treatment cost (\$/yr) [#]
1	1900	57	scum removal in holding tank	90 000
2*	2800	76	scum removal in holding tank	30 000
3	11500	246	drum screen; DAF unit; trickling filter	NA
4*	15000	3800	settling tank; chemical-DAF unit	650 000
5	17500	303	drum screen; chemical-DAF unit	100 000
6*	45000	3600	drum screen; DAF unit	NA

[#] One plant provided very precise figures including municipal surcharge as well as manpower, maintenance and operating costs of in-plant treatment, but most slaughterhouses supplied approximate costs.

* Included some rendering and/or meat processing activities.

Slaughterhouse 5, raw wastewater was sampled six times in eight months. On one occasion, the effluent from the DAF unit was also sampled.

All samples were analysed in duplicate for soluble and total COD (SCOD and TCOD), solid content, ammonia-nitrogen (NH₄-N), total Kjeldahl nitrogen (TKN), volatile fatty acids (VFAs), pH, and alkalinity. Analyses were done according to methods outlined in APHA (1992). Protein concentration was calculated by multiplying the difference between TKN and NH₄-N by 6.25 (AOAC 1984). Volatile fatty acid concentration was determined by gas chromatography. Samples from four slaughterhouses were also analysed for metal and micronutrient content by the inductively coupled plasma (ICP) method at the University of Ottawa, Ottawa, ON.

Data on effluent following in-plant treatment were also made available by Slaughterhouses 3, 4, and 5. At Slaughterhouses 3 and 5, five and ten samples, respectively, were analysed at the plant laboratory over a one-year period. Slaughterhouse 4 collected samples on a bi-monthly basis, and the data covered an 18-month period. Analyses were performed at the plant.

RESULTS and DISCUSSION

Wastewater production and treatment

Johns (1995) suggested that slaughterhouses were fairly efficient in terms of waste recovery and management. This statement is also true of the Canadian meat industry. Most discarded animal parts are sent for further transformation. Screened solids, skin, hair, and unusable interiors (e.g. bad livers, lungs, spleens) are used in cosmetic production; pancreas are kept for penicillin production; blood is dried and transformed into an animal protein feed. Slaughterhouses, however, consume significant amounts of water and thus produce large volumes of wastewater.

Table I presents plant capacity, wastewater production, and in-plant wastewater treatment at the six Québec and Ontario slaughterhouses that were visited between 1995 and 1996. The three plants dealing exclusively in slaughtering activities (1, 3, and 5) produced between 90 and 140 L of wastewater per hog killed. The actual volume of fresh water used per animal killed will be slightly higher since Slaughterhouses 3 and 5 measured

a 10 to 30% loss between water input and wastewater output (data supplied by the plant). However, these slaughterhouses remain fairly efficient water consumers, since water consumption varying between 200 and 600 L per hog slaughtered was reported for German slaughterhouses (Tritt and Schuchardt 1992). The three slaughterhouses combining slaughtering and meat processing activities utilised a higher volume of water, especially Slaughterhouse 4 which included a large

processing plant and thus averaged 1250 L per head killed and processed.

The two smaller slaughterhouses (1 and 2) did not treat their wastewater but stored it for a short period of time in a holding tank, where coarse SS were allowed to settle and floating fat was periodically skimmed off. All other plants had screens or settling tanks for the removal of coarser particles and DAF units for fat and light particle recovery. Slaughterhouse 4 also added ferric chloride and sulfuric acid to the wastewater as it flowed into the DAF unit to induce blood precipitation and flocculation. The pH of the effluent from the chemical-DAF unit was adjusted from 2.7 to 5.5 by mixing it with the wastewater from the meat processing plant. Slaughterhouse 5 used ferric chloride to precipitate proteins and a polymer to flocculate colloids and increase sedimentation. The sludge captured at the top and bottom of the DAF unit was mixed with lime to control pH and smell and shipped out daily for storage or land application, depending on the time of the year. Slaughterhouse 3 used biological aerobic trickling filters to further treat the effluent from the DAF unit. To increase treatment time, microorganisms were added to the holding tank, but the bacteria were killed by lack of oxygen. The plant operator was planning to install emitters to diffuse oxygen in the holding tank. The spray nozzles above the tower had to be washed every morning to remove the scum covering them. Unfortunately, long-term data on the use of trickling towers could not be obtained because the slaughterhouse closed down.

Slaughterhouse 1 had its holding tank periodically pumped out by a private contractor who charged \$90 000 a year for the service. All other slaughterhouses discharged their partially treated wastewater to the city sewer. The municipalities imposed a treatment charge to the slaughterhouses based on various criteria. For example, one municipality calculated surcharge fees based on:

$$\text{Surcharge} = K[0.5TSS + 0.5BOD + 0.2FOG + 0.2N + 0.1P] \quad (1)$$

where:

- K = coefficient based on quantity of wastewater produced and treatment cost at the municipal plant,
- SS = (total suspended solids - 350)/350, where 350 mg/L is the maximum level allowed,

Table II. Raw wastewater quality at six hog slaughterhouses in Québec and Ontario (1995-1996).

Parameters (mg/L except pH)	Slaughterhouse					
	1	2	3	4	5†	6
Total COD	2941	3589	4976	2333	8627 ± 1669	3417
Soluble COD	1510	2605	2817	778	4753 ± 883	1250
Total solids	2244	2727	3862	2747	5748 ± 823	2481
Volatile solids	1722	1966	3153	1204	4458 ± 751	1846
Suspended solids	957	736	1348	877	2099 ± 622	1431
Volatile SS	770	576	1192	594	1887 ± 550	1149
Volatile fatty acids	197	166	221	164	311 ± 34	175
Total Kjeldahl N	174	271	372	90	593 ± 95	158
Ammonia-N	41	154	99	19	169 ± 66	20
Protein	831	731	1700	444	2648 ± 66	856
Phosphorous	20	-	-	28	61	80
Potassium	27	-	-	60	122	56
Calcium	56	-	-	54	15	54
Sodium	54	-	-	369	238	209
Magnesium	25	-	-	17	12	14
Sulphur	54	-	-	49	36	21
Iron	2	-	-	25	7	2
Manganese	0	-	-	2	0	0
pH	6.7	7.2	6.5	4.9	6.9 ± 0.2	6.5
Alkalinity as CaCO ₃	333	333	333	83	906 ± 157	250

† Slaughterhouse 5 was sampled six times in eight months. Except for metals which were analysed in only one sample, the average and standard deviation of the parameters are given in the table.

BOD = (BOD - 300)/300, where 300 mg/L is the maximum level allowed,

FOG = (animal and/or vegetable grease - 100)/100, where 100 mg/L is the maximum level allowed,

N = (Kjeldahl nitrogen - 100)/100, where 100 mg/L is the maximum level allowed, and

P = (total phosphorous - 10)/10, where 10 mg/L is the maximum level allowed.

A second municipality estimated that the local slaughterhouse utilised 80% of the public wastewater treatment facility and had to pay 80% of the cost. In a third case, the municipality evaluated surcharge based on wastewater quantity and quality during three of the most productive days of the year.

Municipal surcharge represented between 10 and 100% of total treatment cost depending on the level and cost of the in-plant pretreatment. Based on the data supplied by the slaughterhouses, overall treatment cost in 1995-1996 ranged from \$0.70 to \$1.60 per m³ of wastewater, except for Slaughterhouse 1, which paid over \$5 per m³. Wastewater treatment at the slaughterhouses also produced a large quantity of sludge requiring special handling and/or further treatment. At the time of the survey, the sludge was hauled to private farms and mixed with manure or compost before it was spread on agricultural fields. Barnett et al. (1997) reported that land application of sludge from meat processing plants had a positive effect on yield, except when the sludge contained high concentrations of

fat. However, if laws governing land application of waste become stricter, as they have for the pork producers, more advanced sludge treatment may be required

Raw slaughterhouse wastewater quality

Table II presents slaughterhouse wastewater quality prior to any treatment, except for the screening or settling of coarser solids. Samples did not include water from the afternoon washing, which would probably dilute the wastewater. However, it also excluded the water from the scalding tank, which is highly charged. Sachon (1986) estimated that the COD content of scalding water ranged from 5000 to 8000 mg/L and represented 20% of the daily polluting load from slaughterhouses.

Total COD in the raw wastewater from the six slaughterhouses varied between 2333 and 8627 mg/L (Table II). At Slaughterhouse 5, where the raw wastewater was sampled six times over an eight-month period, TCOD concentration ranged from 6908 to 11530 mg/L. These TCOD values are similar to those measured in wastewater from hog slaughterhouses in France (4118 ± 1409 mg/L; Sachon 1986) and Germany (between 500 and 10 500 mg/L; Tritt and Schuchardt 1992). Even

though all samples were collected after screening or settling of the coarser solids, SS accounted for 27 to 67% of TCOD. Volatile suspended solids (VSS) represented 80% of the SS and had a COD content of .01 ± 0.36 g per g of VSS. The volatile fraction of the dissolved solids was 65 ± 18%. Protein content ranged from 444 to 2775 mg/L and made up between 37 and 58% of the total volatile solids and 30 ± 7% of TCOD (1.15 g COD per g protein; Sayed et al. 1988). Aside from Slaughterhouse 4, the wastewaters were neutral to slightly acid. They contained between 83 and 900 mg/L of alkalinity as CaCO₃. Alkalinity tended to increase with wastewater strength. In all samples, heavy metal concentration (cadmium, cobalt, nickel, copper, chromium) was below the detection limit. Nitrogen and phosphorous concentrations generally exceeded the limits imposed by municipalities for discharging industrial wastewater to municipal sewers without surcharge (see Eq. 1). However, nutrients and micronutrients (calcium, sodium, magnesium, sulphur, and iron) were in adequate concentrations for a biological treatment of slaughterhouse wastewater. Nitrogen and phosphorous averaged 6.0 and 2.3 g per 100 g of TCOD, respectively, while requirements for biological treatment are estimated at 3 and 0.7% of COD removed, respectively (Grady and Lim 1980). Ammonia-nitrogen and sulfide concentrations were well below the 3000 and 100 mg/L toxicity level, respectively, for the anaerobic biomass (Table II). High levels of light metal cations can be inhibitory to bacteria, but in low

Table III. Effluent quality following preliminary treatment at four slaughterhouses in Québec and Ontario (1995-1996). The values in parentheses were supplied by the slaughterhouse.

Parameters (mg/L except pH)	Slaughterhouse and type of wastewater treatment			
	3 DAF unit trickling filter	4 Chemical- DAF unit	5 Chemical- DAF unit	6 DAF unit
Soluble COD	1598	576	1435	1290
Total COD	3921 (2569 ± 512) [†]	986	3121 (3229 ± 1231) [†]	2325
Total solids	2197	-	3460	1969
Volatile solids	1676	633	2157	1347
Volatile SS	1792	265	1646	682
Suspended solids	1956 (836 ± 770) [†]	422 (226 ± 85) [‡]	1974 (754 ± 471) [†]	893
Volatile fatty acids	673	273	279	110
Ammonia-N	228	19	100	41
Total Kjeldahl N	295 (183 ± 113) [†]	59	269 (268 ± 245) [†]	174
Protein	419	250	1061	831
Fat and grease	(291 ± 316) [†]	(65 ± 35) [‡]	(22 ± 15) [†]	-
Phosphorous	- (28 ± 19) [†]	22 (10 ± 4) [‡]	78 (22 ± 15) [†]	44
Potassium	-	38	214	42
Calcium	-	54	44	42
Sodium	-	404	453	142
Magnesium	-	17	17	12
Sulphur	-	48	63	15
Iron	-	19	43	4
Manganese	-	2	0	0
pH	7.1	5.7	7.0	6.6
Alkalinity as CaCO ₃	667	167	542	167

[†] Based on five to ten samples collected over a one-year period

[‡] Based on bi-monthly samples collected over an 18-month period

concentrations of approximately 75 to 200 mg/L, calcium, sodium (up to 400 mg/L), potassium, and magnesium have stimulatory effects on anaerobic microorganisms (McCarty 1964). Low concentrations of iron also have a beneficial effect on biomass activity (Speece 1996).

Slaughterhouse quality after preliminary treatment

The quality of wastewater as it leaves the slaughterhouse for the municipal treatment plant is presented in Table III. Slaughterhouses 1 and 2 were not included because their wastewater was not treated at the plant. Slaughterhouse 6 had the lowest level of in-plant wastewater treatment. The DAF unit removed approximately 35% of the TCOD and SS, but it did not reduce SCOD, nitrogen, and protein concentrations. There were no other data supplied by the slaughterhouse.

At Slaughterhouse 3, the DAF unit reduced the TCOD and SCOD concentrations by 22 and 16%, respectively. Aerobic

treatment in the trickling towers decreased SCOD by an additional 27% but did not further reduce TCOD, probably because bacteria were sloughed from the filters and left the reactors with the effluent, thus increasing particulate COD. The higher SS concentration in the final effluent, compared to the raw wastewater (Tables II and III), also suggested some biomass losses from the aerobic filters. However, in five effluent samples analysed by Slaughterhouse 3 over a one-year period, average SS concentration was less than half the concentration measured in the effluent sample collected for this survey (Table III). Nevertheless, TCOD in the biologically treated effluent remained high both in the sample collected for this project and in samples analysed by the slaughterhouse laboratory.

At Slaughterhouse 4, the chemical-DAF unit reduced TCOD and SCOD by 58 and 26%, respectively. Over 50% of the SS and 35% of the nitrogen were removed. However, effluent TCOD and SS concentrations were still slightly above the maximum allowable levels for industrial wastewater discharge into municipal sewer without surcharge (see Eq. 1; COD:BOD₅ ratio in slaughterhouse wastewater varies between 1.3 and 2.0 (Sachon 1986; Temper et al. 1988)). Data supplied by Slaughterhouse 4 showed that, over an 18-month period, the effluent had a BOD₅ concentration varying between 400 and 500 mg/L and an SS content between 200 and 300 mg/L. Slaughterhouse 4 had the most dilute raw wastewater and the weakest effluent. However, it had the highest water consumption, probably because of the meat processing activities. The municipal surcharge for wastewater treatment was kept low, but the cost associated with water input was high.

Slaughterhouse 5 had the most efficient treatment system; the chemical-DAF unit removed 67% of TCOD and SCOD. However, effluent TCOD and SS concentrations remained high at 3121 and 1974 mg/L, respectively. The effluent TCOD data supplied by the slaughterhouse laboratory were similar to those measured in this survey (Table III). Effluent from Slaughterhouse 5 was among the most polluted, but its raw wastewater was also 2 to 3 times stronger than that from other slaughterhouses.

CONCLUSION

Raw wastewater from hog slaughterhouses in Québec and Ontario contained high concentrations of degradable organics. Existing wastewater treatment at all surveyed slaughterhouses was not sufficient to produce an effluent that complied with municipal treatment plant criteria and usually generated large volumes of sludge. Consequently, slaughterhouses had to pay surcharge fees to municipalities to further treat their wastewater and had to dispose of the sludge. Wastewater treatment costs can only increase in the future since they depend on municipal taxation level and on the price of non-renewable chemical input.

Hog slaughterhouses produce a wastewater that is suitable for anaerobic treatment in terms of BOD, nutrient, and micronutrient concentration. However, hydraulic retention time would have to be sufficient to allow for the degradation of the SS, which represented between 27 and 67% of TCOD.

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