Characterization of provincially inspected slaughterhouse wastewater in Ontario, Canada

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Wu, P.F. and G.S. Mittal. 2012. **Characterization of provincially inspected slaughterhouse wastewater in Ontario, Canada.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada. 54: 6.9-6.18. Characteristics of slaughterhouse waste-water and its suitability to be land-applied for agricultural use were investigated. A survey was sent to slaughterhouses located in Ontario, Canada, and their methods of disposal were determined. Wastewater samples were taken from randomly selected slaughterhouses and were analyzed for their chemical constituents. The meat type, presence of blood and the commodity type had a highly significant impact on the biological oxygen demand (BOD5), total Kjeldahl nitrogen (TKN) and total solids (TS). As TKN and BOD5 can be decreased by the reduction of TS in the wastewater, it is important that the slaughterhouses remove as much TS from the wastewater as possible. The presence of blood increased Co and Mo levels in the wastewater. The concentrations of 11 metals present are very low and if the wastewater is land applied properly, the risk to the environment is minimal. **Keywords:** Abattoir, land application, meat plant, slaughterhouse, wastewater.

Cette étude a porté sur les propriétés des eaux usées d'abattoirs et sur la possibilité d'épandre ces eaux sur des terres agricoles. Un sondage a été envoyé à tous les abattoirs situés en Ontario, Canada dans le but de déterminer les méthodes utilisées pour la disposition de leurs eaux usées. Des échantillons d'eaux usées ont été prélevés à un certain nombre d'abattoirs choisis de façon aléatoire dans le but de déterminer leur composition chimique. Le type de viande, la présence de sang et le type d'animal ont tous eu un impact très significatif sur la demande en oxygène biologique (BOD5), l'azote total Kjeldahl (TKN) et les solides totaux (TS). Puisque la TKN et la BOD5 peuvent être réduits par une réduction des TS dans les eaux usées, il est important que les abattoirs enlèvent le plus possible de TS de leurs eaux usées. La présence de sang a provoqué une augmenta-tion des niveaux de Co et de Mo dans les eaux usées. Les concentrations de 11 métaux présents étaient très faibles et si les eaux usées sont épandues de façon appropriée, les risques pour l'environnement sont minimaux. **Mots clés**: abattoir, épandage, usine de transformation de viandes, eaux usées.

INTRODUCTION

Waste materials generated from the slaughterhouse operations include inedible materials such as offal, hides, blood, wastewater, garbage from stomach and intestine and sanitary septage. Wastewater is generally collected in a retention tank beneath the kill floor, with storage capacity varying from plant to plant. Water is used for the scalding, chilling, dehairing, defeathering, washing and rinsing of carcasses, and the cleaning of processing equipment. Worldwide, slaughterhouses are facing the tasks of treating and disposing of wastewater and residues (Munak 2002). Water consumption is dependent upon the type of animal slaughtered and processing operation. The wastewater may contain soil, animal fecal material, animal tissue, blood, hair/feathers and food grade cleaning agents. Worldwide legislations on regulating the disposal of slaughterhouse wastewater and solid waste are not yet uniform (Mittal 2007). European and North American regulations impose minimum land-application restrictions for water and soil protection (Mittal 2007). The Nutrient Management Act, 2002 (OMAFRA 2002), and subsequent modifications, prescribe standards for all land applied materials containing nutrients. To develop standards specific to land applied slaughterhouse wastes, there is a need to better understand the quality of the wastewater in terms of available N, P, K and toxicity.

There were 184 slaughterhouses and 60 free standing meat plants in Ontario licensed under the Food Safety & Quality Act, 2001 (Government of Ontario 2001) as of January 23, 2006. All slaughter operations that are not federally registered must be licensed under this Act. Meat plants slaughtering and processing meat and meat products, are classified into two main plant categories – red meat and white meat. The water usage requirement varies with Massé and Masse (2000) reporting an average of 90 to 140 L per hog killed for slaughterhouses located in eastern Canada. Tritt and Schuchardt (1992) reported that slaughterhouses in Germany generated 200 to 600 L of wastewater per hog, and 1000 to 1500 L of wastewater per cattle. Stebor et al. (1990) reported that 400 to 3100 L of wastewater was generated per animal. In general, poultry slaughtering operations use more water, producing lower strength of the wastewater (Mittal 2004).

Presently, in Ontario, land application of wastewater generated from slaughterhouse falls under the Environmental Protection Act (OMAFRA 1996) and the determining factors for suitability are the same factors used for sewage, and pulp and paper biosolids. A system for treating high strength slaughterhouse wastewater (Rivera et al. 1997) consisted of an anaerobic digester followed by wetland using flow through the root zone of hydrophytes planted in a gravel substrate. The overall removal efficiencies were 88.5% for biological oxygen demand (BOD), 87.4% chemical oxygen demand (COD), 89% suspended solids (SS), 73.6% organic nitrogen and >99% faecal coliforms. Therefore slaughterhouse wastewater is many times pre-treated before land application (Johns 1995; Mittal 2006). Pre-treatments are screening, catch basins, flotation, equalization, and settlers. About 40–60% of the solids or about 25–35% BOD load can be separated by screening and sedimentation (Mittal 2006).

Del Pozo et al. (2000) characterized poultry wastewater, and Massé and Masse (2000) characterized wastewater from hog slaughterhouses. Tritt and Schuchardt (1992) provided the wastewater characteristics for beef and hog separately. The strength and quantities of the wastewater vary from day to day, and from slaughterhouse to slaughterhouse as well. Since slaughterhouse wastewater has high chemical constituents loading and is made up of about 45% soluble and 55% coarse suspended organics (Nunez and Martinez 1999), some municipalities impose surcharges on treating slaughterhouse wastewater. Meat plant wastewater quality depends on water usage, type of animal slaughtered, and the amount of rendering or processing done on site (Mittal 2004). In Ontario and Quebec, Canada, slaughterhouse wastewater COD ranged from 2333 to 8627 mg/L, and SS from 736 to 2099 mg/L, volatile suspended solids (VSS) represented 80% of SS, and protein content from 444 to 2775 mg/L. Slaughterhouse wastewater may contain several million colony forming units (cfu)/100 mL of total coliform, fecal coliform, and *Streptococcus* groups of bacteria (Mittal 2004).

Massé and Masse (2000) reported that one municipality calculated surcharges based on quantity of wastewater produced and treatment cost at the sewage treatment plant (STP), SS, BOD, fat oil and grease (FOG), nitrogen (N) and total phosphorus (TP). Another STP in south-western Ontario imposed their surcharge based on a 7 day rolling average of the BOD. Hence, BOD, TSS, FOG, N and P are some of the parameters to be monitored. Under the Environmental Protection Act, the monitoring of parameters such as BOD and SS are not required.

There has been some research completed to characterize the wastewater from slaughterhouse operations (Mittal 2004), however most of the data has been generated from large-scale operations and does not include all the parameters required to determine the suitability of the materials for land application. There is also an information gap on the level of 11 metals regulated under the Environment Protection Act (OMAFRA 1996), and the Nutrient Management Act, 2002. Therefore, the objective of this study involved collecting information representative of the Ontario slaughterhouses, relative to storage and disposal of wastewater, blood separation and wastewater handling practices. For this, a survey of provincial inspected slaughterhouses was also conducted, and wastewater was characterized after collecting samples.

MATERIALS and METHODS

Survey

A survey was conducted to determine meat plant wastewater disposal profiles of provincially-inspected slaughterhouses. The questionnaire included information such as species of animals slaughtered, average yearly slaughter rates, wastewater storage methods and holding capacity, methods currently used to handle wastewater, frequency of removal (if hauled), quantity of wastewater generally removed, and the method of final disposal by the hauler. One hundred and ninety survey questionnaires were sent out to effective slaughterhouses operating under the Meat Inspection Act (Ontario), and a total of 136 surveys were returned for an overall response rate of 70%. Sixty-five percent of poultry slaughterhouses responded compared to 72% of red meat slaughterhouses. The high survey response rate was possible with the help of meat inspectors of OMAFRA.

Slaughterhouse wastewater samples were collected based on the type(s) of species slaughtered and the type of operation over an 18 month period. The categories of operations included: beef, hog, poultry, sheep and goat slaughter, and mixed species. Sampling sites were chosen based on the questionnaires completed in the profile component of the study. A minimum of 3 samples, each from different days of operations were collected from 6 slaughterhouses for each category of operation. All wastewater samples were collected at the end of the processing operation so that sample can represent day's wastewater.

Sampling procedure

Using the Nabber pole for average sample: One litre sterile bottle was attached to the end of a nabber pole. Nabber pole was dipped into the wastewater at the desired level. Wastewater was poured into sampling bucket once the jar was full. The total sample collected in the bucket should be representative of the wastewater in the entire retention tank. Therefore, samples were taken from a symmetrical pattern that covers the entire depth of the tank and as much of the width as possible. This continued until the sample bucket contained approximately 8 L of material.

Using the COLIWASA*:* The COLIWASA extension was attached where ceiling height permitted for tanks more than 6' deep. Ensuring that the stopper was disengaged, the COLIWASA was slowly lowered into the tank until it touched the bottom. The ball, attached to the end of the metal pole, was firmly pulled up to engage the stopper, then the COLIWASA was lifted out of the tank, and placed its bottom end in the sampling bucket. The stopper was released by pushing on the ball, allowing the COLIWASA to empty into the bucket. This was repeated until there was approximately 8 L of wastewater in the bucket.

Using a 1 L jar and a stir rod, the wastewater was transferred from the bucket to the sample jars. The depth of wastewater was recorded, and pH, conductivity and dissolved oxygen (DO) levels in the wastewater were measured using the 1 L jar. Ten drops of nitric acid were added to two bottles for metal analysis, marking these with an (A) on the lid. The mercury analysis bottle (green lid) required 3 drops of acid and 3 drops of potassium (orange bottle). There were six 500 mL PET bottles, one 250 mL green-lidded glass jar for mercury analysis, and one 250 mL yellow-lidded glass jar for FOG analysis. Using bleach, water and a sponge, the sampling devices (COLIWASA or nabber pole), 1 L jar, sampling bucket and the exterior of each of the sample jars were cleaned. The sample jars were placed into a cooler with ice packs or ice.

Wastewater analysis

Characterization included: COD, BOD_5, total solids (TS), total Kjeldahal nitrogen (TKN), ammonia and ammonium nitrogen, nitrite and nitrate nitrogen, total phosphorus, total potassium, total sodium, pH, the 11 metals specified in the Ontario regulations (OMAFRA 1996), and FOG.

The samples were sent to the Ontario Ministry of the Environment (MOE) laboratory for analysis. All samples were put in an insulated styro-foam box and packed with icepacks. They were kept at or below 4°C. Once the laboratory received the samples, validated methods were used for the analyses. All methods used for the analysis of different parameters are listed in Table 1. The 11 metals that are regulated under the environment protection agency (EPA) and their prescribed limits are listed in Table 2. More details on regulations of these methods are given by Mittal (2007). These 11 metals were also analyzed from the wastewater samples obtained from slaughterhouses in Ontario. ANOVA with GLM procedures were used for the analysis of data, and the ranking of means was done using Duncan's procedure of Statistical Analysis System version 9.1 (SAS 2006). The independent variables were: Meat types – red and white, wastewater with and without blood, 7 sample locations, and commodity type – beef, pork, poultry, sheep/goat, mixed, and further processing. The dependent variables were chemical and biochemical parameters of the wastewater such as COD, FOG.

RESULTS and DISCUSSIONS

Table 3 provides typical operations for beef, hog and poultry processing. In a beef slaughterhouse, once the animal is rendered unconscious, operators will shackle the animal and hoist it to the bleeding rail. After the animal is stuck with a knife, blood will flow freely from the animal to the floor. In some slaughterhouses, there is a blood pit installed underneath the bleeding area to collect the blood. If a blood pit is not installed, the blood will drain and it will be mixed with the wastewater. In a small plant, when the beef cow stops bleeding, the operator will lower the animal onto a cradle (or dressing bed) for skinning. In a medium sized beef, the operator will install an automatic hide puller to remove the hide. The beef head removed from the carcass is washed and the nasal cavities are flushed with water. After the carcass is approved for human consumption, it will normally be split into two halves. A final rinse will be applied before the carcass is moved into the drip cooler. The carcass will stay in the drip cooler for approximately 24 h at 4°C to 10°C (Government of Ontario 2001).

In a hog slaughterhouse, animals are stunned electrically or with carbon dioxide, shackled separately onto a chain, bled and scalded whole at 60°C for 6 min. The hog is then dehaired mechanically and by flame,and polished by hand or machine to remove any hair or charred particulates left on the carcass. After approval, the carcass is split into halves, rinsed and chilled to 4°C within 24 h.

In a white meat slaughterhouse, birds are hanged onto a shackle, electrically stunned, slash the neck with a rotary disc, bled in a trough, scalded, defeathered and thoroughly rinsed. Besides opening up the carcass and presenting the viscera to the meat inspector for disposition, the carcasses can also be cut up prior to chilling. Legs, feet, wings, are some of the typical parts that are separated.

Water is used extensively for slaughtering operations after the stunning and killing processes. In a beef slaughterhouse, water is used for carcass washing after hide removal, evisceration, and final rinse. In hog slaughtering, water is used for scalding, dehairing, polishing, evisceration, washing and final rinse. In a poultry slaughterhouse, water is used for scalding, defeathering, evisceration, chilling and final rinse.

Respondent profile component

Type of slaughter

Forty-four slaughterhouses specialized in one specie. There were 8 beef, 10 pork, 22 poultry, 2 sheep and 2 rabbit slaughterhouses. The remaining 92 were mixed species slaughterhouses, for beef, pork, sheep, poultry, rabbit, elk, emu, ostrich, buffalo, deer, pigeons and quail. The size of the plants varied considerably, slaughtering

Table 1. Methods used for analyzing various slaughterhouse wastewater parameters.

Method number	Equivalent APHA number	Parameters
MOE-E3091	3114	Arsenic, selenium
MOE-E3181	3030F	Calcium, chromium, cobalt, copper, lead, molybdenum, nickel, zinc
MOE-E3182	5010B	BOD_5
MOE-E3188	2540B	Total solids
MOE-E3218	2510B	Electrical conductivity, pH
MOE-E3246	5220	COD
MOE-E3301	3112B	Mercury
MOE-E3217	3111B	Calcium, magnesium, sodium, potassium
MOE-E3366	4500	Ammonia nitrogen, nitrite nitrogen, nitrite+nitrate nitrogen, phosphorus
MOE-E3368	$4500N_{org}$ D	Total Kjeldahl nitrogen, total phosphorus
MOE*	5520D	Fats, oils and greases

*= No method number assigned to this method; MOE = Ministry of Environment; APHA = American Public Health Association; Unit for all except EC and pH is mg/L.

Table 2. Standards for regulated metals in materials applied to land that are not sewage biosolids (OMAFRA 1996).

Regulated metals	Maximum annual loading (kg/ha/yr)	Maximum cumulative loading (kg/ha)	Maximum concentration in materials applied to land (mg/L)
Arsenic	0.28	1.4	1.70
Cadmium	0.05	1.6	0.34
Cobalt		30.0	3.40
Chromium	4.70	210.0	28.00
Copper	2.70	150.0	17.00
Mercury	0.02	0.8	0.11
Molybdenum		4.0	0.94
Nickel	0.70	32.0	4.20
Lead	1.80	90.0	11.00
Selenium		2.0	0.34
Zinc	6.70	330.0	42.00

anywhere from 50 to 550,000 animals per month (Fig. 1). The 112 slaughterhouses for red meat indicated numbers between 50 and 9,000 animals, with 63% slaughtering under 200 animals per month. The 22 poultry slaughterhouses slaughtered between 1,000 and 550,000 birds per month, with 60% of those slaughtering over 10,000 birds (Fig. 2).

Blood collection

When blood is collected during slaughtering, it reduces the BOD and odour. Sixty two percent surveyed slaughterhouses collected blood separately. Once the blood was collected, 74 of 85 slaughterhouses sent it to rendering and 11 composted blood on the premises.

Wastewater

Chill tanks are found only in poultry slaughterhouses. Scald tanks are used for poultry, pork and in some cases, sheep slaughterhouse as well. Thirty-six slaughterhouses surveyed had settling tanks pumped or skimmed out by renderers. This type of operation was more common for poultry. Two out of 136 plants surveyed utilized grease trap for fat separation. Out of 136 plants, 53% of them did not treat their wastewater prior to disposal (Fig. 3). Sixteen percent used treatment systems such as dissolved air floatation or aeration. The remaining 31% of slaughterhouses with a treatment utilized passive systems such as storage tank or lagoon to settle solids.

Storage methods

Six percent of the slaughterhouses did not store the wastewater and the drainage of these slaughterhouses were directly connected to the sewage treatment plant. Eighty percent of the slaughterhouses stored the wastewater in a retention tank prior to disposal and the remaining slaughterhouses stored the wastewater in lagoons or ponds. The sizes of these tanks varied from 3,000 to 750,000 L.

Method of disposal

Fifteen percent of the slaughterhouses disposed the wastewater at the STP. Nine percent of the slaughterhouses were directly connected to the STP and 6% of them used a hauler to haul the wastewater to the STP. Eleven percent of the slaughterhouses used leaching bed for the disposal of the wastewater. An additional 21% used both the

Table 3. Typical beef, pork and poultry slaughtering processes.

Operation number	Beef	Hog	Poultry
1	Receive live animals	Receive live animals	Receive live animals
2	Stun	Stun	Hang
3	Stick	Stick	Stun
4	Shackle	Shackle	Stick
5	Hoist	Hoist	Scald
6	Dehide	Scald	Defeather
7	Hoist	Dehair	Rehang
8	Eviscerate	Singe	Eviscerate
9	Final rinse	Polish	Chill
10	Chill	Eviscerate	Chill
11	Cut & debone	Final rinse	Package
12	Wrap	Chill	Ship
13	Ship	Cut & debone	
14		Wrap	
15		Ship	

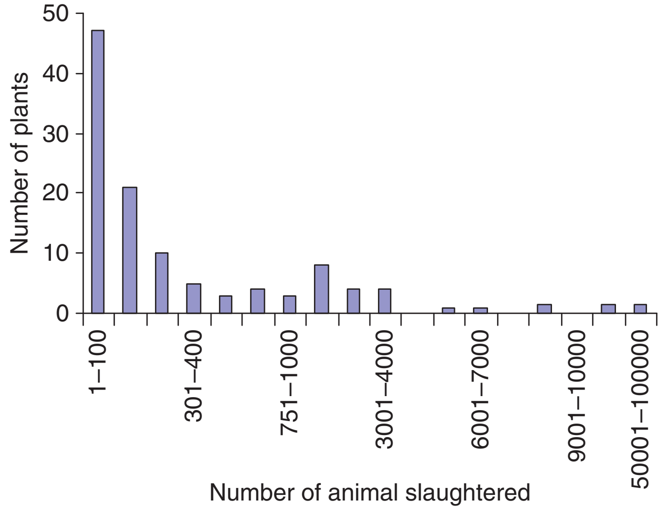

Fig. 1. Slaughter statistics per month for red meat and mixed slaughterhouses.

leaching bed and haulers to dispose of the wastewater. Forty three percent of the slaughterhouses land applied the wastewater. Of the 43% that land applied, 33% of them used hauler to land apply the wastewater. Fifty three percent of them land applied the wastewater on premises and the remaining 14% land applied elsewhere.

Frequency of land application

The frequency of land application varied from slaughterhouse to slaughterhouse and was mainly affected by the size of the storage facility and the slaughterhouse operating capacity. However, close to half of the slaughterhouses that land applied the wastewater stored the wastewater for no more than one month prior to land application (Fig. 4). This implied that these slaughterhouses land applied the wastewater year round.

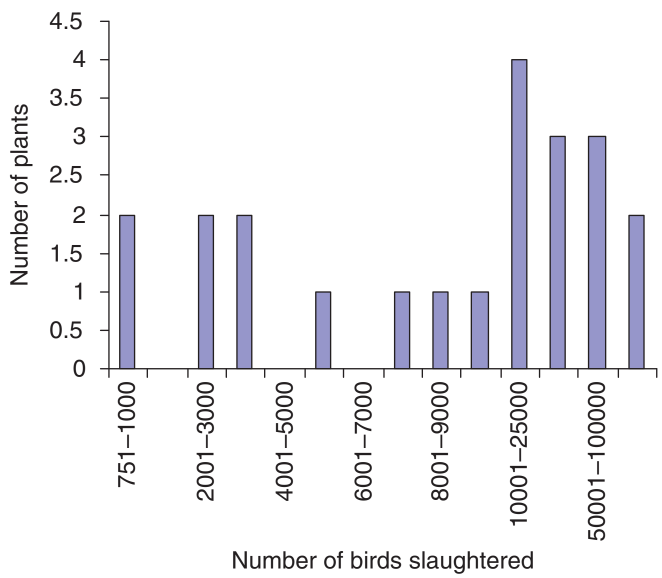

Fig. 2. Slaughter statistics per poultry slaughterhouses.

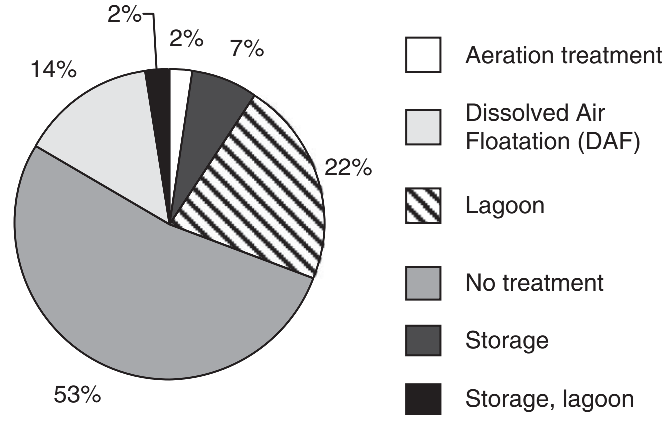

Fig. 3. Wastewater treatment methods used by slaughterhouses.

Wastewater characterization

There were 224 wastewater samples taken from 6 provincially licensed slaughterhouses at the time of study. The overall results are shown in Table 4, and Table 5 provides the results based on livestock type. Table 6 shows the ANOVA results. Results of these tables are discussed below.

Total solids (TS)

The overall mean TS was 6394 ± 6625 mg/L and the overall median was 4500 mg/L (Table 4). The meat type and the presence of blood had a highly significant impact ($P < 0.0001$) (Table 6). International studies (Mittal 2004) reported TS and VSS in the ranges of 220–6300 (highest in a study from Brazil) and 270–13411 mg/L (largest from a Nigeria study), respectively. Since the slaughterhouse wastewater contained bio-digestible materials such as

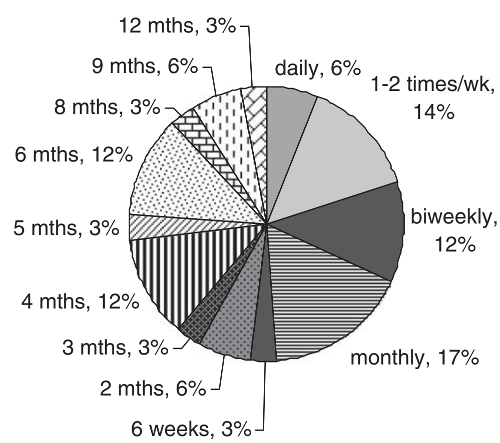

Fig. 4. Frequency of land application of wastewater by the slaughterhouse; mths = months.

meat scrap and blood, removing these by screening and separate collection will reduce the TS and BOD loads and odours. Best management practices for solids management can remove manure from the floor before washing. The meat scraps can be disposed of by rendering, composting,

Table 4. Meat plant wastewater results from selected provincially inspected slaughterhouses in Ontario (MDL = minimum detection limit).

Parameters (mg/L, except*)	Results			
	Number of samples	Mean	Standard deviation	Median
pH*	220	6.98	0.63	6.98
BOD_5	219	4635	6114	2480
COD	217	11588	30103	5070
TS	218	6394	6625	4500
EC* (mS/cm)	182	5662	4451	4505
Nitrogen – nitrite, nitrate	157	8.59	66.94	< MDL
Nitrogen – ammonia, ammonium	193	63.66	85.87	32.8
TKN	219	841	958	539
TP	220	48.4	61.9	30.2
P_2O_5	191	21.4	25.2	15.1
K	218	91.1	90.7	73.5
Ca	218	66.9	60.8	47.3
M	218	31.8	52.2	20.3
Na	218	621.0	1443.7	279.5
FOG	220	1302	3282	< MDL
As	220	0.0252	0.00255	< MDL
Cd/Co/Hg	205/208/131	< MDL	< MDL	< MDL
Cr	210	0.21807	0.13588	< MDL
Cu	217	0.41	0.69	< MDL
Pb	208	0.21	0.08	< MDL
Mo	209	0.13	0.18	< MDL
Ni	207	0.21	0.07	< MDL
Se	220	0.03	0.00	< MDL
Zn	220	1.22	2.54	0.55

MDL for Co, Cr, Cu, Pb, Ni, Cd, Zn were 0.2 mg/L, for Hg was 0.005, for Se were 0.025, for Mo was 0.1, for N from nitrate and nitrite was 0.25, and for FOG was 500 mg/L.

burial or incineration instead of land application. This was dependent on how well the operators separated the meat scraps, manure, and blood from the wastewater. Hence, the separation of blood and improved handling of offal and manure are highly recommended for slaughterhouses that intend to land apply the wastewater.

Table 5. Meat plant wastewater results from six provincially inspected slaughterhouses in Ontario based on commodity and blood mixed with wastewater.

Parameters	Values for wastewater with blood for different commodity					
	Beef	Mixed	Pork	Poultry	Processing	Sheep/goat
pH	7.0 ± 0.4	6.9 ± 0.6	7.0 ± 0.6	7.0 ± 0.3	9.2 ± 0.7	6.9 ± 0.2
BOD_5	14545 ± 5802	8231 ± 9636	4711 ± 2356	1648 ± 859	45 ± 1	6250 ± 1796
COD	50665 ± 83866	15256 ± 17072	10010 ± 6188	3341 ± 2234	860 ± 594	9145 ± 1351
TS	15694 ± 6554	9938 ± 10107	5862 ± 2693	2097 ± 822	1255 ± 389	8880 ± 1725
EC	9577 ± 8483	7503 ± 5223	3565 ± 1679	3685 ± 600	864 ± 235	5125 ± 516
N	1.8 ± 1.1	33.8 ± 159.2	1.0 ± 1.7	< MDL ± 0	< MDL ± 0	0.5 ± 0
N’	116 ± 170	50 ± 51	43 ± 96	111 ± 101	0.4 ± 0.2	7 ± 3
TKN	2310 ± 1017	1541 ± 1454	736 ± 366	432 ± 199	11 ± 1	927 ± 1
TP	86 ± 52	77 ± 96	35 ± 15	34 ± 14	6 ± 2	82 ± 50
P_2O_5	47 ± 19	26 ± 43	15 ± 7	26 ± 10	2 ± 1	40 ± 35
K	187 ± 81	110 ± 76	156 ± 219	66 ± 33	10 ± 4	130 ± 56
Ca	48 ± 25	58 ± 45	76 ± 48	26 ± 25	19 ± 13	56 ± 31
Mg	23 ± 12	20 ± 11	33 ± 22	16 ± 12	8 ± 2	34 ± 3
Na	2325 ± 5666	558 ± 505	204 ± 59	290 ± 289	136 ± 30	979 ± 624
FOG	2427 ± 3386	2111 ± 4180	1521 ± 4160	< MDL ± 0	< MDL ± 0	< MDL ± 0

N = N from Nitrate and nitrite, N’ = N from ammonia and ammonium

Table 6. ANOVA using GLM procedure for various parameters of wastewater.

Source	Df	Pr > F													
		BOD_5	COD	TS	EC	N	N'	TKN	TP	P_2O_5	K	Na	FOG	Cr	Mo
Model	12	***	0.217	***	0.013	***	0.023	***	0.038	0.797	***	0.202	0.707	0.870	0.731
Meat type	1	***	0.052	***	0.003	0.550	0.017	***	0.018	0.935	0.011	0.068	0.135	0.029	0.385
Blood	1	***	0.055	***	0.877	0.540	0.919	***	0.004	0.449	***	0.834	0.098	0.641	0.040
Sample location	6	0.161	0.853	0.161	0.575	***	0.475	0.244	0.519	0.418	***	0.982	0.942	0.991	0.992
Commodity	4	0.020	0.246	0.014	0.018	0.632	0.013	0.041	0.526	0.884	0.153	0.024	0.699	0.931	0.519
Error	211														
Total	223														

N = N from Nitrate and nitrite, N' = N from ammonia and ammonium, *** = Pr > F is <0.0001, no effect of these independent variables on other metals (Cu, Pb, Co, Hg, Ni, Se, Zn, As and Cd); df = degree of freedom.

pH

The overall mean pH was 6.98 ± 0.63 with a median of 6.98 (Table 4). This pH range is comparable to previous studies (6 to 10) (Mittal 2003, 2004). The minimum range is reported from Holland and Spain, and larger range from Germany and Newzealand. The pH was highly affected by the amount of chemicals used for cleaning and by water usage. The pH was significantly impacted by the sample location ($P < 0.05$) (Table 6). The sample location could be the lagoon, the retention tank, or the holding tank. The age of the wastewater varied at these locations. The allowable pH range for wastewater discharge to the environment is usually around 6.5 to 8.5 (Tchobanoglous et al. 2003). With regards to land application, MOE determined the pH level of the material between 6.0 and 8.5 when it is applied to an established crop. Any material that has a pH level beyond the given range can be applied to agricultural land only before planting or after harvest, when crops are not present. The pH values obtained were within the range acceptable to MOE for land application to an established crop.

Biochemical oxygen demand (BOD_5)

In a pork slaughterhouse, water was used for scalding and dehairing whereas in a beef slaughterhouse, dehiding took the place of scalding and dehairing. The mean BOD_5 value for pork wastewater samples was lower than the mean BOD_5 value for beef because the overall water usage in the pork slaughterhouse was higher than in the beef (Table 4).

The overall mean BOD_5 value was 4635 ± 6114 mg/L with a median of 2480 mg/L (Table 4). The meat type, the presence of blood and the sample spot had a highly significant impact on the BOD_5 ($P < 0.0001$) (Table 6). The BOD values reported by previous studies ranged from 199 to 4633 mg/L (Mittal 2003, 2004); however, not all authors reported BOD_5 results. Lower range is provided by a study from Spain and larger ranges from Holland and India. Applying high BOD_5 materials on the land surface may cause odour problems. The legislation in Ontario has not established a guideline for the acceptable BOD_5 levels for material to be land applied. However, the issue of odour as a nuisance is addressed under the Environmental Protection Act.

The overall mean COD was 11588 ± 30103 mg/L and the median was 5070 mg/L (Table 4). The COD from previous studies ranged from 530 to 11118 mg/L (Mittal 2003, 2004). Large ranges were provided from studies conducted in Canada and Holland. The meat type and the presence of blood had a significant impact at the 90% level on the COD. The COD/BOD_5 ratios for the different types of wastewater based on their mean values are given in Table 7. The COD/BOD_5 ratios of wastewater with blood were lower than the COD/BOD_5 ratios of wastewater without blood. It was caused by higher BOD_5 level in wastewater with blood than wastewater without blood. The mean and median COD/BOD_5 ratios from all wastewater samples were 2.88 and 2.04, respectively. The ratio also indicates that COD is much higher (1.49 to 4.80 times) than BOD_5 for all wastewater.

Table 7. COD/BOD_5 ratio based on commodity type.

Commodity	COD/BOD_5 ratio	
	Blood	No Blood
Beef	1.87	2.18
Pork	2.39	3.18
Sheep	1.49	2.15
Mixed	2.64	2.99
Poultry	2.19	4.80

Nitrogen

The results for the analysis of various types of nitrogen were reported on the basis of nitrite nitrogen and nitrate nitrogen (NO_2-N and NO_3-N), ammonia and ammonium nitrogen (NH_3-N and NH4-N), and total Kjeldahl nitrogen (TKN). The amount of nitrogen in the wastewater was affected by various factors (Tables 4 and 5). The presence of blood and the meat type had a highly significant impact on the TKN level ($P < 0.0001$) (Table 6). Mittal (2003, 2004) reported wide variation in TKN and NH_4N in the ranges of 44–700 mg/L and 3–740 mg/L, respectively. The sample spot had a highly significant impact on the amount of nitrite nitrogen and nitrate nitrogen in the wastewater ($P < 0.0001$). The meat type and the commodity type had a significant impact on the ammonia nitrogen and ammonium nitrogen. Collecting the blood during slaughtering and reducing the amount of organics in the wastewater will reduce TKN. This can be achieved by precipitation of the solids in the wastewater followed by filtration (Mittal 2006).

The samples were taken from various locations such as septic tanks, total retention tanks, secondary tanks, ponds or lagoons just prior to land application. Different types of storage facilities provided different retention time. Some of the wastewater samples were taken immediately from the retention tank after the slaughtering was completed. Alternatively, the samples were taken from storage facility such as lagoon where the denitrification process had taken place to reduce the presence of nitrite and nitrate.

Phosphorus and phosphate phosphorus (P_2O_5)

Total phosphorus (TP) exists in wastewater as phosphate in the form of orthophosphate and polyphosphate. High amount of soluble orthophosphate is harmful to aquatic life. The mean and median TP for beef, sheep, mixed species and poultry wastewater with blood were higher than the samples without blood (Table 4). The mean TP of pork wastewater with blood was lower than without blood. The presence of blood and the meat type had a significant impact on the TP ($P < 0.05$) (Table 6). The amount of phosphate phosphorus was not affected by the meat type, the presence of blood, the sample spot or the commodity type. Mittal (2003, 2004) reported phosphorous range of 6–175 mg/L, and the largest range in the study was from Nigeria (115–175 mg/L).

Potassium and sodium

The presence of blood and sample spot had a highly significant impact on the potassium level ($P < 0.0001$). The meat type had a significant impact as well ($P < 0.05$) (Table 6). The mean sodium concentration was 621 ± 1443 mg/L and the median was 280 mg/L (Table 4). The commodity type had a significant impact on the sodium level ($P < 0.05$). The presence of blood, meat type and sample locations had no significant impact on the mean sodium value.

Fat, oil and grease (FOG)

Neither the meat type nor the commodity type had any impact on the level of FOG in the wastewater (Table 4). Mittal (2003, 2004) reported the largest range of FOG of 40–600 from a study from Brazil. The ANOVA with GLM results show that FOG was not affected by the sample location as well. The median FOG of beef and pork wastewater without blood was below minimum detection limit (MDL = 500 mg/L), and with blood was 888 mg/L and MDL respectively. The median showed that FOG levels for the beef and mixed species wastewater with blood were higher than beef and mixed species wastewater without blood, but the presence of blood in wastewater had no significance on the FOG level.

Electrical conductivity (EC)

The average EC value was 5662 ± 4451 mS/cm, the median was 4505 mS/cm, and the range was 1000 to 13000 mS/cm (Table 4). Only 5 wastewater samples had EC values < 1000 mS/cm, and 43 samples had 1000 to 3000 mS/cm. The median for pork wastewater without blood was 5185 mS/cm and with blood was 3340 mS/cm. The meat type and commodity type had significant impact on the EC level ($P < 0.05$) (Table 6). When blood was collected during the slaughtering, the mean EC of the beef was not significantly different than pork, sheep and mixed specie wastewater. However, when blood was not collected, the mean EC for beef wastewater with blood was significantly different than pork and poultry wastewater with blood. The mean EC for processing wastewater was lower from other types of wastewater. The EC provides information on soluble salts such as K, Mg, Ca, and Na. The presence of salts affects the water uptake efficiency of the crops. MOE and United States Environmental Protection Agency (USEPA) restrict the use of wastewater for irrigation when the EC is greater than 700 mS/cm. Slaughterhouse wastewater is highly odorous and is therefore, not suitable for irrigation. Land application of high sodium wastewater is permitted only if the soil sodium and soil EC are monitored annually.

Metals

The presence of blood had a significant impact on the level of Co and Mo ($P < 0.5$). Unfortunately, blood samples from animals slaughtered were not taken from those slaughterhouses. Hence, the level of Co and Mo might be affected by other environmental factors such as the type of stainless steel being used in the slaughterhouses or the Co or Mo level in the water used. The meat type had a significant impact on the level of Cr ($P<0.05$) (Table 6). Other metals levels are not affected by any independent variable studied (Table 6). Not much data is available on these metals in the literature. Since no meat tissue samples were taken when the wastewater samples were taken, it can not conclusively suggest that meat tissues contained any metals. The level of metals in the slaughterhouse wastewater samples are shown to be lower than the limits stipulated under the legislation in Ontario. Metal behaviour in soils and plant uptake is difficult to generalize. If a more precautionary approach to toxic metal addition to the soil is to be taken, studies of the behaviour of each metal in each specific situation would have to be performed. Land application of wastewater is a common practice by slaughterhouse operators. Several larger slaughterhouses have approvals from the MOE to land apply the wastewater on agricultural land.

Overall results and further work

Overall, based on the ANOVA with GLM results, the meat type had a highly significant impact on the BOD_5, TKN, and TS ($P<0.0001$) and a significant impact on the Cr, ammonia and ammonium nitrogen, TP, K and EC ($P<0.05$). The presence of blood had a highly significant impact on the BOD_5, TKN, K and TS ($P<0.0001$) and a significant impact on Co, Mo, and TP ($P<0.05$). The commodity type had a significant impact on the BOD_5, ammonia and ammonium nitrogen, TKN, TS, EC and Na ($P<0.05$). The sample location had a highly significant impact on the nitrite nitrogen and nitrate nitrogen, and K ($P<0.0001$) and a significant impact on the pH ($P<0.05$) (Table 6).

There are concerns about the presence of pathogenic microorganisms in slaughterhouse wastewater. There are also concerns about the odour that may be generated from land applying the wastewater. These two topics should be further investigated and quantified. Further studies should also be conducted to evaluate the performance and economic impact of various types of wastewater treatment methods. Mittal (2003, 2004) reviewed the work conducted in these areas around the World. Limited data is available on pathogens in slaughterhouse wastewater. However slaughterhouse wastewater may acquire pathogens naturally from hides and digestive tracts of the slaughtered animals. Few countries have provided acceptable pathogens levels in wastewater for land application. France and Italy allow spreading of biosolids containing up to 0.8 and 1000 most probable number (MPN) of Salmonella per g of dry matter respectively. Regulations are proposed for Entrovirus, Entrobacteria, and parasites in some countries.

CONCLUSIONS

The meat type had a highly significant impact on the BOD_5, TKN, and TS and a significant impact on the Cr, ammonia and ammonium nitrogen, TP, K and EC. The presence of blood had a highly significant impact on the BOD_5, TKN, K and TS and a significant impact on Co, Mo, and TP. The commodity type had a significant impact on the BOD_5, ammonia and ammonium nitrogen, TKN, TS, EC and Na. The sample spot had a highly significant impact on the nitrite nitrogen and nitrate nitrogen, and K and a significant impact on the pH.

As the TKN and the BOD_5 can be decreased by the reduction of TS in the wastewater, it is important that the slaughterhouses remove as much total solids from the wastewater as possible. This will reduce the odour and the impact on the environment. The concentration of heavy metals present in slaughterhouse wastewater is very low. The blood significantly increased the Co and Mo levels in the wastewater.

LIST OF SYMBOLS

ANOVA	Analysis of variance
BOD or BOD_5	Biochemical oxygen demand
CFIA	Canadian Food Inspection Agency
DO	Dissolved oxygen
COD	Chemical oxygen demand
EC	Electrical conductivity
EPA	Environmental Protection Act, R.R.O. 1990
FOG	Fats, oils and greases
GLM	General linear modeling
MDL	Minimum detection limit
MOE	Ontario Ministry of the Environment
MPN	Most probable number
OMAF	Ontario Ministry of Agriculture and Food
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
SAS	Statistical Analysis System
SS	Soluble solids
STP	Sewage treatment plant
TDS	Total dissolved solids
TKN	Total Kjeldahl nitrogen
TP	Total phosphorus
TS	Total solids
TSS	Total suspended solids
USEPA	United States Environmental Protection Agency
VSS	Volatile suspended solids

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