Treatment of wastewater from abattoirs before land application—a review

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Abstract

Pre-treatments are screening, catch basins, flotation, equalization, and settlers for recovering proteins and fats from abattoir wastewater. With chemical addition, dissolved air flotation (DAF) units can achieve chemical oxygen demand (COD) reductions ranging from 32% to 90% and are capable of removing large amounts of nutrients. Aerobic trickling towers reduced soluble COD by additional 27% but did not reduced total COD. Chemical-DAF reduced 67% of total COD and soluble COD. About 40–60% of the solids or approximately 25–35% of the biological oxygen demand (BOD) load can be separated by pre-treatment screening and sedimentation. Anaerobic systems are lagoon, anaerobic contact (AC), up-flow anaerobic sludge blanket (UASB), anaerobic sequence batch reactor (ASBR), and anaerobic filter (AF) processes. Abattoir wastewater is well suited to anaerobic treatment because it is high in organic compounds. Typical reductions of up to 97% BOD, 95% SS and 96% COD are reported. UASB's average COD removal efficiencies are of 80–85%. UASB seems to be a suitable process for the treatment of abattoir wastewater, due to its ability to maintain a sufficient amount of viable sludge. Wastewater in abattoirs can be reduced by treatment of immersion chiller effluent by membrane filtration which can produce recyclable water. Total organic C can be reduced below 100 mg/L, and bacteria can not pass through the membrane pores. The abattoir waste minimization options are also discussed.

Keywords: Abattoir; Smokehouse; Wastewater; Treatment; Land application; Land spreading

1. Introduction

The common methods for disposal of blood by meat processors are rendering, land application, composting and transfer to a wastewater treatment plant. In the United States (US), the federal government provides guidance while state governments regulate composting and land application. Rendering is defined as the process of breaking, through heat application, blood, meat pieces and other animal byproducts to useful components. Rendering plants are closing due to the reduction of feedstock supply and user demand. Rendering plants are now start charging a disposal fee for blood. Due to this, rendering is now less attractive and less economical. Composting and land application are alternatives for rendering (US-EPA, 2002).

Composting is a biological decomposition of organic matter (blood or other animal or vegetable products) and can be accelerated by providing correct temperature, moisture content, density and feedstock mixture. The resulting product is a nutrient-rich material that can be used as fertilizer or soil conditioner. Composting methods are: open-air plies and windrows, to self-contained drums, vessels, and anaerobic digesters. Only a few commercial composting units are accepting blood. The composting of animal products (except manure)

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requires higher level permit and rigorous standards than composting of municipal yard waste. McGill composting (Harrells, North Carolina, USA) estimated a cost of US$25/ton for disposal and an additional charge of US$4–10/ton for transportation if the processor is within 160 km of the composting facility. For the disposal of rumen and stomach contents and screenings containing fat and flotation trailings, composting is a suitable method (Tritt and Schuchardt, 1992). On-site composting is an alternative for meat processors who are unable to find someone who is willing to accept blood and is cost effective. On-site composting requires know-how, capital investment, sufficient space and regular maintenance. Any type of method specified above can be used. Windrow composting requires less capital investment but large space and maintenance. In-vessel composter requires lesser amount of space and man-power. But for small processors, the initial cost might be prohibitive.

In land application, the biological material is directly put into the land either by injection or by other mechanical means. The materials are biodegradable and provide nutrients to soils. In Canada, land application is not feasible throughout year due to subfreezing temperatures. Thus, in most parts of Canada, considerable amount of wastewater would require to be stored during the winter months. Advantages of land application are (Massé and Massé, 2000a): (i) recovery of wastes, (ii) replacement of chemical fertilizers (N, P, K), and (iii) soil structure improvements. The limitations are: (i) public visual nuisance and odour, (ii) surface and groundwater pollution, (iii) soil, contamination due to toxic, heavy metals and organic compounds, and (iv) health hazards to human and animals due to pathogens. Other environmental effects are: (i) acid and greenhouse gases emissions, and (ii) net primary energy consumption associated with treatment, storage and transportation.

Abattoirs in Ontario and Quebec provinces of Canada generally discharge their wastewater in municipal sewers after some degree of primary or chemical pretreatment at the plant. Abattoirs are therefore required to pay a surcharge to dispose their wastewater for further treatment at the municipal treatment plants (Massé and Massé, 2000b). Except in Scandanavia, there are a few waste treatment plants installed at abattoirs across Europe.

There are three types of wastewater treatments (Massé and Massé, 2000b): (i) primary treatment—separation of floating and settleable solids using screening, catch basin, dissolved air flotation (DAF) and flow equalization, (ii) secondary treatment—removal of organic matter using lagoons, activated sludge systems, extended aeration, oxidation ditches and sequencing batch reactors, and (iii) tertiary treatment—removal of N or P or suspended solids of some combination.

2. Preliminary treatments

Pretreatments are screening, catch basins, flotation, equalization, and settlers for recovering proteins and fats. Screens or filters can be used to remove suspended solids in wastewater. After filtering, the water may be reused. Solid particles may include fat, bone, hair and meat lost during the slaughtering process. The strainers are made of metal wire and can intercept particles of various sizes depending on strainer mesh size. Most strainers rely on gravity to separate out the coarser particles. Coarse strainers have openings ranging from 6 to 25 mm; fine screens have openings less than 6 mm. Often, fine screens are used after coarse screens to further remove solids. Manure can be separated from the wastewater and can be treated as a solid waste. Similarly, separated fat from wastewater can also be considered a solid waste or by-product. Types of screens used are: static, rotary drum, brushed and vibrating.

Catch basins or settling tanks also remove grease and finely suspended solids by gravity. The minimum standards for new plant construction require a 30×30 cm metal, PVC or fiberglass basin. Solids heavier than water sink to the bottom and grease and fine solids rise to the surface. A skimmer is used to remove grease and scum off the top and a scraper to remove sludge from the bottom. Typical biological oxygen demand (BOD) removal is from 25% to 40% and soluble solids (SS) removal is 50–70%. Due to very high BOD of blood, it is desirable to collect the maximum amount of blood so that wastewater BOD load can be reduced (Johns, 1995).

3. Primary treatments

Following preliminary treatment, the effluent can undergo primary or secondary treatment. A popular method of primary treatment is the DAF system. DAF is a common method to reduce effluent load of fat, suspended solids and BOD. However, other methods can achieve the similar results at low-cost. In DAF, air bubbles injected at the bottom of the flotation tank, transport light solids and other material such as fat and grease, to the surface where the scum is consistently skimmed off. DAF can separate very small or light particles more completely and in a shorter time compared to gravity settling. In this process, entire or a fraction of the influent or effluent is saturated with air at 250–300 kPa and then introduced into a flotation tank. Chemicals such as polymers and flocculants are often mixed prior to DAF process for better performance. Blood coagulants (e.g. aluminum sulphate and ferric chloride) and/or flocculants (e.g. polymers) are added to wastewater to increase protein clumping and precipitation as well as fat flotation. With chemical addi-

Table 1
Raw abattoir (SH) wastewater versus effluent quality following preliminary treatments (adapted from Massé and Massé, 2000a)

Parameters mg/L except pH	SH3 raw	SH3 DAF unit trickling filter	SH4 raw	SH4 chemical 1-DAF unit	SH5 raw	SH5 chemical 1-DAF unit	SH6 raw	SH6 DAF unit
Total COD	4976	3921	2333	986	8627 ± 1669	3121	3417	2325
Total COD	2817	1598	778	576	4753 ± 883	1435	1250	1290
Total solids	3862	2197	2747	–	5748 ± 823	3460	2481	1969
Volatile solids	3153	1676	1204	633	4458 ± 751	2157	1846	1347
Suspended solids	1348	1956	877	422	2099 ± 622	1974	1431	893
Volatile SS	1192	1792	594	265	1887 ± 550	1646	1149	682
Volatile fatty acids	221	673	164	273	311 ± 34	279	175	110
Total Kjeldahl N	372	295	90	59	593 ± 95	269	158	174
Ammonia-N	99	228	19	19	169 ± 66	100	20	41
Protein	1700	419	444	250	2648 ± 66	1061	856	831
Fat and grease	–	291 ± 316	–	65 ± 35	–	22 ± 15	–	–
Phosphorous	–	–	28	22	61	78	80	44
Potassium	–	–	60	38	122	214	56	42
Calcium	–	–	54	54	15	44	54	42
Sodium	–	–	369	404	238	453	209	142
Magnesium	–	–	17	17	12	17	14	12
Sulphur	–	–	49	48	36	63	21	15
Iron	–	–	25	19	7	43	2	4
Manganese	–	–	2	2	0	0	0	0
pH	6.5	7.1	4.9	5.7	6.9 ± 0.2	7.0	6.5	6.6
Alkalinity as $CaCO_3$	333	667	83	167	906 ± 157	542	250	167

Heavy metal concentrations (cadmium, cobalt, nickel, copper, chromium) were below detectable limits. Nitrogen and phosphorous exceeded the limits imposed by municipalities. Nutrients and micro-nutrients (calcium, sodium, magnesium, sulphur and iron) were in adequate concentration for a biological treatment of abattoir wastewater. The wastewater did not include scald tank water.
(–): Indicates that no information is available.

tion, DAF units can achieve chemical oxygen demand (COD) reductions ranging from 32% to 90% and are capable of removing large amounts of nutrients (Johns, 1995). Massé and Massé (2000a) compared the characteristics of wastewater after preliminary and primary treatments (Table 1). DAF reduced about 35% of total COD (TCOD) and SS, but did not remove soluble COD (SCOD), N and protein concentrations. Aerobic trickling towers reduced SCOD by additional 27% but did not reduced TCOD. Chemical-DAF reduced 67% of TCOD and SCOD.

Inline flow equalization tanks are installed to avoid the necessity of sizing subsequent treatment units to handle peak flows and loads. Odour can be controlled by using biological scrubbers and adsorption beds which are alternatives to chemical scrubbers. Sedimentation is a common primary treatment technique used to separate solids from wastewater influent. About 40–60% of the solids or approximately 25–35% of the BOD load can be separated by pre-treatment screening and sedimentation (Marriott, 1999).

3.1. Coagulation flocculation process

Ferric sulphate, $Al_2(SO_4)_3$ and polyaluminum chloride were used as coagulants to treat abattoir effluent (Aguilar et al., 2002). Inorganic products were used as coagulant aids including silica, powered activated carbon, precipitated calcium carbonate, synthetic polyelectrolytes, cationic polyacrylamide polyacrilic acid, anionic polyacrylamide and polyvinyl alcohol. Phosphorus removal was very high (approximately 100% for the orthophosphate, and between 98.93% and 99.90% for the total phosphorus). Ammonia nitrogen removal was very low, although appreciable performances are observed for albuminoid nitrogen (73.9–88.8%). The use of coagulant aids reduces the sludge volume up to 41.6%. The removal of phosphates through chemical precipitation is affected by alkalinity, organic matter and the presence of other metals. The nitrogen (albuminoid) is removed by the removal of colloidal matter. Coagulation–flocculation processes have been applied for treating abattoir wastewater (Nunez et al., 1999). Three compounds: aluminum sulphate, ferric chloride and polyaluminum chloride ($PACl_2$) were used as coagulants. Maximum TCOD removal rates were 45–75%. The best results were obtained when using $PACl_2$ as reagent. The results obtained with compounds varied widely with pH.

4. Secondary treatments

Biological treatments remove organic compounds and pathogens from the effluent using microorganisms. Biological treatments can remove greater than 90%

pollutants from wastewater. The reduction of BOD and total SS (TSS) can be accomplished by aerobic or anaerobic means, with suspended growth or attached growth treatment processes. Suspended growth processes maintain the microorganisms in suspension within the liquid by mixing. Attached growth processes, also known as fixed film processes, have the microorganisms attached to some static medium, such as ceramic or plastic materials. Both processes require sufficient contact time between the wastewater and the microorganisms. Detergents and chemicals used in the abattoir operations should be suitable for the biological treatment processes (EPA, 2000).

Red stream from slaughter yard, and green stream from tripe processing and pen cleaning (Sendic, 1995) were treated. Red stream contained blood, and these two streams were differentiated by their sources and physicochemical parameters given below. System used 2–5 mm mesh self-cleaning static screens, a flotation system with pressurized air injection in each stream, a 1300 m^3 volume reactor with six baffled modules, and two lagoons of 7000 m^3 and 10,000 m^3 each. The compositions were as follows:

	TCOD, mg/L	SCOD, mg/L	VSS, mg/L	Fats, mg/L	TKN, mg/L	P, mg/L
Red	6700	2412	1600	1200	268	17
Green	21,000	3570	10,000	1700	525	68

VSS = volatile SS, TKN = total Kjeldahl nitrogen.

High content of TSS and fat in wastewater could produce solids accumulation and/or flotation of active biomass; causing a complete loss of efficiency in the high-load anaerobic process. Primary treatment efficiencies are given below. The increase of agitation with the recycle, increases the suspended solids degradation.

	Screens		Flotation	
	Green	Red	Green	Red
Insoluble COD removed, %	60	25	38	71
Fats removed, %	20	15	37	63

4.1. Anaerobic treatments

Anaerobic systems are not used in Canada presently for treating abattoir wastewater (Massé and Massé, 2000a). BOD can be reduced using the microbially mediated reduction of organic compounds to methane and CO_2. These processes are more sensitive to changes in temperature and loading rate compared to aerobic processes. Included in this category are lagoon, anaerobic contact (AC), up flow anaerobic sludge blanket (UASB), anaerobic sequence batch reactor (ASBR), and anaerobic filter (AF) processes. Abattoir wastewater is well suited to anaerobic treatment because it is high in organic compounds (Tritt, 1992; Massé and Massé, 2000a; Caixeta et al., 2002). Anaerobic treatment reduces organic compounds to methane and CO_2 by bacteria in the absence of oxygen. Anaerobic treatment of pig abattoir wastewater is often complicated by the presence of particulates and fats (Batstone et al., 1997). Recovery of fat and solids can be improved using chemical addition. AC systems tend to circumvent the floating-scum problem. The anaerobic treatment systems will be more effective if fats and suspended solids are removed by pre-treatment. Hydrolysis rates of fats depended on fatty acid chain length, state (solid or liquid) and specific surface area (Batstone et al., 2000a). Protein hydrolysis rates depended on whether the protein is globular or fibrous, surface area and solubility. Reductions of 30–40% CO_2 and 60–70% methane are reported by US-EPA (2002). Anaerobic systems are highly efficient at reducing COD in both soluble and insoluble forms. They achieve a high-degree of BOD removal. The methane can be recovered and used as an energy source (Batstone et al., 2000a,b). Two types of systems exist: low-rate (lagoons) and high-rate.

4.2. Low-rate systems

Anaerobic lagoons are popular for the treatment of abattoir wastewater in the USA and Australia, since climate conditions and land availability allow the construction of large lagoons (Johns, 1995). A typical anaerobic lagoon is between 3 and 5 m deep with a retention time of 5–10 d. Influent wastewater flow is usually near the bottom of the lagoon and has a pH between 7.0 and 8.5. It is not mechanically mixed, although some gas mixing can occur. A scum usually develops at the surface, reducing heat loss and thus ensuring anaerobic conditions. Anaerobic lagoons can handle a wide variety of waste characteristics. Typical reductions of up to 97% BOD, 95% SS and 96% COD are reported by US-EPA (2002).

Meat processing wastewater contained high-levels of organic N_2 (70–250 g/m^3). In New Zealand, anaerobic and aerobic stabilization ponds are commonly used to treat this wastewater, but their ponds typically remove less than 35% of the nitrogen (Bickers and Oostrom, 2000). Anaerobic lagoons have threatened their continued use due to odour regeneration. To trap odour and biogas, anaerobic ponds were covered with synthetic floating covers (Johns, 1995). Covering lagoons reduces heat losses with the result of higher microbial reaction rates (US-EPA, 2002). In Canada, lagoon covers must be strong enough to withstand ice, wind and snow accumulation. The efficiency of anaerobic lagoons is greatly reduced below 21 °C (Hammer and Jacobson, 1970). A two stage system for treating high-strength wastewater from an abattoir consisting of an anaerobic digester followed by an artificially constructed wetland (Rivera et al., 1997). The treatment efficiency during the 12 mo period was generally good with mean removal efficiencies of 88.5% for BOD, 87.4% for COD, 89% for TSS, 73.6% for organic N, and greater than 99% faecal coliforms reduction. Raw wastewater contained $BOD_5 = 1700$ mg/L, TSS = 1500 mg/L and faecal coliforms = 1.8×10^6–5.4×10^{12}/100 mL.

4.3. High-rate systems

For wastewater treatment, advanced high-rate anaerobic processes can be used to achieve better performance, reduce effluent loading and reduced emissions. To determine the acceptable water quality for recycling, online BOD monitors can be utilized. High-rate anaerobic reactors have been developed to accelerate treatment and reduce area required, especially in Europe and Asia. Suspended growth processes include anaerobic contact reactors and anaerobic sequencing batch reactors. Up flow anaerobic sludge blanket (UASB) processes use granules to capture bacteria. Attached growth anaerobic processes include anaerobic fixed filter reactors.

4.3.1. Up flow anaerobic sludge blanket (UASB) reactor

In UASB reactors, the influent enters at the bottom of the digester, flows upward through a compact layer of bacteria (the sludge blanket) and exits at the top of the reactor. Basically it consists of three phases—liquid, solid (the sludge or biomass), and gas (gases formed during the digestion process, predominantly CO_2 and CH_4). As the gas forms, it flows upward, transporting particles to the top of the reactor (Ruiz et al., 1997). These should return to the sludge blanket so they remain inside the reactor. Successful operation depends on the formation of bacterial flocs or granules that accumulate and easily settle at the digester bottom (Massé and Massé, 2000a). Manjunath et al. (2000) reported that flocculent sludge removed more insoluble COD whereas granular sludge removed SCOD more efficiently. Reactor operation requires close supervision. A good fat separator should be installed to prevent excessive scum layers in the reactor (Sayed et al., 1993; Manjunath et al., 2000). UASB's average COD removal efficiencies are of 80–85%, and are efficient when operated with an organic loading rate (OLR) in the range of 2.7–10.8 kg COD/m^3/d.

Successful high-rate anaerobic degradation of abattoir wastewater has been demonstrated largely in hybrid UASB/filter combinations (Ruiz et al., 1997; Borja et al., 1998). Two CSTR (completely stirred tank reactor) with UASB reactor in series were used. A full scale, two stage hybrid up flow anaerobic reactor, treating pig abattoir effluent was assessed (Batstone et al., 2000b). Results have indicated that it is very difficult to degrade protein based particulate substrate, and longer solids residence times are required. Hydrolysis of fats was rate limiting rather than conversion of fatty acids to acetic acid. In UASB, average influent COD was of 5100 mg/L. Results supported the use of Monod equation for this process (Borja et al., 1994). In UASB, COD removal varied from 77% to 91% while BOD removal was 95% (Caixeta et al., 2002). The removal of TSS varied from 81% to 86%. It operated for 80 d with hydraulic retention times (HRTs) of 14, 18 and 22 h.

Hansen and West (1992) evaluated an UASB for treating abattoir wastewater. The influent was 2% blood/98% condensate (phase 1), and 56% wash-up water per 44% condensate (phase 2). Chemical oxygen demand for both phases was 5300 mg/L. Hydraulic retention-time varied from 5.2 to 15.6 d. Chemical oxygen demand removal efficiencies for phase 1 ranged from 28% to 72%, and phase 2 from 72% to 87%. The methane production was 0.2–0.25 L/g COD converted in phase 1, and 0.28–0.34 L/g COD converted in phase 2. Total soluble solids varied from 220 to 1600 mg/L, and VSS varied from 210 to 1500 mg/L.

Red water was from slaughter area, green water was from tripe processing and pen cleaning, and sewage water was from toilets (Martinez et al., 1995). A flotation system by pressurized air injection was tested. The fat removal efficiency obtained was 63% and 37% for red water and green water, respectively. To improve the hydrolysis of particulate matter, a system of two UASB reactors with recirculation, connected in series, was evaluated. Removal efficiency was 77% for SCOD and 82% for insoluble COD at a volumetric load of 1.8 kg COD/m^2/d.

Sayed and de Zeeuw (1988) also used an UASB to treat abattoir wastewater at 30 °C. Compared to several anaerobic treatment processes, the UASB seems to be a suitable process for the treatment of abattoir wastewater, due to its ability to maintain a sufficient amount of viable sludge, thereby providing efficient and stable treatment. The wastewater was collected after passing through a screen installed to remove the dispersed particles larger than 1 mm. Sayed et al. (1993) also used two stage high-rate UASB to treat abattoir wastewater. The maximum sludge stabilization at 30 °C was approximately 50% for the accumulated coarse suspended solids and colloidal fractions in the reactors. The length of sludge stabilization period was 14 d. UASB performance in treating abattoir wastewater is provided in Table 2 (Rodriguez-Martinez et al., 2002).

Manjunath et al. (2000) used a DAF–UASB (dissolved air flotation–up-flow anaerobic sludge blanket) at 30 °C ± 1 °C to treat abattoir wastewater with the following characteristics: pH = 6.5–7.3, TSS = 300–2300 mg/L, BOD = 600–3900 mg/L, fat = 125–400 mg/L, TKN = 90–150 mg/L, phosphate = 8–15 mg/L, and COD = 1100–7250 mg/L. DAF–UASB is a feasible system for the treatment of abattoir wastewater. The proposed system is an appropriate alternative to the two

Table 2
Performance of UASB in treating abattoir wastewater (adapted from Rodriguez-Martinez et al., 2002)

	COD, mg/L	pH	Sulphate, mg/L	Phosphate, mg/L	VSS, mg/L	TSS, mg/L
Influent	12,820	7.5	970	410	26,500	58,200
Effluent	1430	8.2	240	250	3550	5660
% removed	88.8	–	75.3	39	86.6	90.3

	VFA (acetic acid), mg/L	Alkalinity as $CaCO_3$, mg/L	Fat, mg/L	Kjeldahl N, mg/L	Nitrates, mg/L
Influent	880	530	250	531	0.96
Effluent	325	580	120	150	0.21
% removed	63.1	–	52	71.8	78.1

(–): Indicates that no information is available.

Table 3
Performance of UASB reactor for granular sludge to treat abattoir wastewater (adapted from Sayed et al., 1987)

Temperature (°C)	Organic space load	Treatment efficiency	Conversion of removed colloidal and soluble materials into methane, %	Hydraulic retention time, h
30	11 kgCOD/m^3/d	55% COD (total) 85% COD (filtered)	87	9
20	7 kgCOD/m^3/d	56% and 68%	82	10

stage UASB system. DAF unit reduced waste strength by about 50%. At HRT of 10 h, COD removal was 90%. Sayed et al. (1987) in Netherlands, evaluated a UASB reactor for granular sludge to treat abattoir wastewater. The results are provided in Table 3.

An anaerobic contact reactor (ACR) consists of a stirred tank reactor followed by a sludge separator. In concept, ACR systems are similar to the activated sludge process. The system can maintain a long solids residence time at a relatively short HRT. An ACR operated at 32.5 °C and received pre-settled wastewater at organic loading rates (OLRs) ranging from 0.12 to 0.28 kg/m^3/d (Black et al., 1974). Reduction in BOD was approximately 90% and volatile solids reduction ranged between 41% and 67%.

An anaerobic sequencing batch reactor (ASBR) requires low capital and operating costs and minimum daily maintenance. Abattoir wastewater was treated in a 42 L ASBR at 30 °C. The wastewater influent contained TCOD from 6908 to 11,500 mg/L. Total COD was reduced by 90–96% at OLRs of 2.07–4.93 kg/m^3/d and HRT of 2 d. Soluble COD was reduced by 95%. The biogas contained 75% methane (Massé and Massé, 2000b). In an ASBR, the feeding, reacting, settling and decanting all occur in the same vessel. The need for complete mixing is eliminated, however, there will be intermittent mixing during the react cycle (Massé and Massé, 2000a).

Anaerobic fixed film reactors (AFFR) are cylindrical or rectangular tanks that have built-in devices to retain bacteria. The most common type of packing used is corrugated plastic. Chemical oxygen demand reduction was 76–95% at an OLR of 1.4 kg/m^3/d (del Pozo et al., 2000). This is a very appropriate system for pre-treatment of wastewater with high-organic load and high-solids concentrations like abattoir wastewater (Borja et al., 1994). In the AFFR, for treating poultry wastewater, COD removal efficiencies ranging from 85% to 95% were observed for organic loading rates of 8 kg COD/m^3/d, while the highest organic loading rates (35 kg COD/m^3/d) led to efficiencies of 55–75% at 35 °C (del Pozo et al., 2000).

The anaerobic filters (AF) operate as an attached growth or fixed film reactor and is a column filled with various types of media. AF with random support have been successfully used for wastewater treatment, where COD removal efficiencies of 80–90% were obtained for organic loads up to 22–25 kg COD/m^3/d. (Borja et al., 1993; Henze and Harremoes, 1983). The treatment efficiency of the AF processes was affected by wastewater temperature and HRT; with higher operating temperatures, higher loading rates were possible (Viraraghavan and Varadarajan, 1995, 1996). Efficiency increased when the temperature was increased even at the same HRT. The following data were reported: HRT = 0.8–4.9 d, temperature = 23.6–27.1 °C, COD loading rate = 1194–5900 COD mg/L, COD effluent = 446–372 mg/L, and COD removal = 37–77%.

Anaerobic sequencing batch reactors (ASBRs) eliminate the need for complete mixing and is a variation of the contact process. Massé et al. (2001) used ASBR for treating abattoir wastewater. Influent COD and TSS averaged 7500 and 1700 mg/dm^3, respectively. Reactor start up was completed in 168 and 136 d at 20 and

25 °C, respectively. Effluent quality varied throughout start up, but in the last 25 d, as ASBRs were operated under OLRs of 2.25 ± 0.21 and 2.86 ± 0.24 kg/m^3/d at 20 and 25 °C, respectively, and total COD was reduced by 90.3 ± 1.3%.

Nunez and Martinez (1999) used EGSB (expanded granular sludge bed) reactor to treat abattoir wastewater at 35 °C. The averaged COD removal percentages were 67% for total OLRs up to 15 kg COD/m^3/d and HRT of 5 h. Total SS were 90% removed for total solids loads of 6 kg TSS/m^3/d. Fats were removed by 85%. The anaerobic treatment of wastewater in an EGSB system appeared to be a feasible option.

4.3.2. Aerobic treatments

Aerobic treatment involves the degradation of organics by microorganisms in the presence of oxygen. The systems require daily maintenance by a trained technician and daily drainage of accumulated sludge (Massé and Massé, 2000a). Microorganisms require free dissolved oxygen to reduce the biomass in the wastewater. The biological sludge must be treated before disposal (Johns, 1995). Aerobic treatments are very effective at reducing odours and pathogens (Skjelhaugen and Donantoni, 1998). These include aerobic lagoon, activated sludge processes—conventional, extended aeration, complete mix, oxidation ditches, sequencing batch reactors (SBRs), and trickling filters and rotating biological contactors (RBCs). The aeration tank is a plug flow reactor in the conventional process. A complex mix tank, as an aeration basin, is used in complete mix activated sludge process. Extended aeration works in the endogenous respiration phase of the microbial growth curve. A ring or oval shaped channel is used in the oxidation ditch, and is equipped with mechanical aeration devices.

Aerobic treatment can directly follow primary treatment. Massé and Massé (2000a) and US-EPA (2002) suggested some form of anaerobic treatment with aerobic treatment to further reduce BOD, SS and ammonia concentrations. Aerobic systems require large space, maintenance, management, and energy requirement for artificial oxygenation. Primary-treated abattoir wastewater contains high-concentration of organic carbon (e.g. COD/TKN ratios 20–25:1), which requires high-aeration and sludge-disposal costs if wastewater is treated using an aerobic treatment. Lagoons and various forms of activated sludge process are examples of suspended growth processes; trickling filters and rotating biological contactors are examples of attached growth processes (Johns, 1995; US-EPA, 2002).

Aerobic lagoons are large shallow earthen basins that use algae in combination with other microorganisms for wastewater treatment. Oxygen is supplied naturally by the wind, through photosynthesis and by mechanical means. These lagoons are shallower than anaerobic lagoons so that the light can penetrate full depth. Biological oxygen demands reductions are up to 95%, but effluent SS concentrations are often elevated because of poor sludge settling. Intermittent mixing is necessary. Oxygen requirements and treatment time increase steeply with wastewater strength. US-EPA (2002) reports loading rates in the range of 4.5–135 kg of BOD per acre per day with an HRT of 3–10 d. Constructed wetlands improve the quality of the effluents with respect to faecal indicator microorganisms, chemical, BOD and TSS. Nitrogen removal in the planted wetlands during the final year of the study was approximately twice that in the wetland without plants, and averaged 46–49% (5.2–5.5 g N/m^2 d) at a high-average loading rate of 11.2 g N/m^2 d (van Oostrom, 1995). Summer time N removal reached 75%, 87% by the planted wetlands was due to denitrification.

Activated sludge processes are commonly used in the US. Processes include conventional, complete mix, extended aeration, oxidation ditch and sequencing batch reactor. The sludge is maintained by continually recycling a fraction of the settleable solids separated after aeration back to the aeration basin. These settled solids contain an active microbial population, which aggregate to form flocs. The remaining sludge is removed from the system and may be stabilized using aerobic or anaerobic digestion or lime stabilization. This is capable of 95% reductions in BODs (US-EPA, 2002).

A bed of highly permeable media is used in a trickling filter where a microbial flora is attached; a distribution system spreads wastewater over the bed surface, and a drain system collects treated wastewater. Trickling filters consist of a non-submerged fixed-film using rock or plastic packing over which wastewater is distributed continuously. Filter beds are usually round and the depth ranges from 4 to 12 m. Treatment occurs as the liquid flows over the attached biofilm. Depth of the packing ranges from 0.9 to 2.5 m. Slime layer depth is 10 mm. Bacteria in the slime layer enter endogenous respiration state and lose their ability to cling to the packing surface. The liquid then washes the slime off the packing and a new slime layer starts to grow. Reported BOD efficiencies with plastic packaging are in the range of 60–90% (US-EPA, 2002).

RBC uses an attached microbial film to absorb and metabolize organic matter, provides energy and nutrients for microbial growth and maintenance. A combined chemical coagulation/ flocculation FBBR (fluidized bed biofilm reactor) was used for treating abattoir wastewater (Li et al., 1986). Alum with supplemental use of ferric chloride and an anionic polymer yielded: 5 d BOD 24–53%, grease 66–80%, and TSS 62–73% removal performance. Performance improved with increasing feed BOD, grease and TSS concentrations. Food to microbial ratio (FM) of 1.45–9.25 kg/kg/d, empty bed hydraulic retention time of 8.8 to 30.8 min, and feed BOD concentration of 305–602 mg/L were used. The observed

BOD, grease and NH_3-N removals were 71–93%, 29–84% and 20–73%, respectively. More than 70% of feed BOD, grease and NH_3-N could be removed up to an PM ratio of 2 kg/kg/d at 25 °C ± 2 °C.

4.4. Other methods

Sayed et al. (1988) used conventional stirred batch digesters at 20 and 30 °C to treat membrane-filtered, paper filtered or not filtered abattoir wastewater. The maximum biodegradabilities found at 30 °C were 61–75%, while at 20 °C, these were 49–72%. The maximum biodegradability of the coarse suspended solids fraction of the waste was 50% at 30 °C, and 45% at 20 °C. Tritt (1992) used fixed bed reactor in Germany to treat abattoir wastewater. At loading rates of 2–18.5 g/L d and HRTs of 5 to 0.5 d, biological efficiency achieved was on average, 30–85% for COD using bamboo as carrier, and 27–80% for COD using bone as carrier.

Various sludge treatments are: chemical—liming with slaked lime (26% and 62%) and quick lime (25%) (Gantzer et al., 2001); thermal treatment (drying at 108 °C); and biological—mesophilic stabilization, anaerobic mesophilic digestion, aerobic thermophilic digestion, and composting. Pasteurized activated sludge from pig abattoirs can be effectively fermented into a stable product, suitable for animal feed purposes (Fransen et al., 1998). The rendering plants process abattoir waste materials to produce animal feed additions. An activated sludge plant with anoxic stage was constructed to provide nitrification-denitrification with phosphate removal by post-precipitation (O'Flynn, 1999). Nitrogen can be removed by biologically denitrification (Russell et al., 1993), and for this, readily metabolisable organic carbon must be present. Rendering stick water and paunch liquor contain large amounts of readily biodegradable COD, with a maximum of 315 mg/L in paunch liquor and 2145 mg/L in stick water, and thus sustained high-initial denitrification rates. Wastewater contains little or no significant amounts of readily biodegradable COD, resulting in slower denitrification rates.

The summary of the performance of various secondary treatments is given in Table 4. The methods used for pathogen inactivation in biosolids are given in Table 5. The distribution of wastewater treatment units in US-MPP industry is provided in Table 6. Primary treatments include screening, DAF and flow equalization. Secondary and tertiary treatments used are biological treatments, filtration and disinfection.

5. Tertiary treatments

Tertiary treatment refers to the removal of suspended or dissolved substances. Nutrients like nitrogen and phosphorus can be removed by biological treatment or physicochemical methods, often within existing treatment plants. Due to high-cost involved, their use in treating abattoir wastewater is limited.

6. Appropriate technology

For the Meat and Poultry Products (MPP) industry direct effluent discharges, Environmental Protection Agency (EPA) is proposing regulations based on the best practicable control technology currently available (BPT), the best conventional pollutant control technology (BCT), the best available technology economically achievable (BAT), and the best available demonstrated control technology for new source performance standards (NSPS) (US-EPA, 2002). Revised effluent limitations guidelines and standards (ELGs) are being proposed for 9 of 10 existing subcategories of the meat products industry. EPA is also proposing two new MPP subcategories with effluent guidelines and source performance standards for poultry slaughtering (first processing) and further processing categories. The agency is not proposing any new or revised effluent limitations guidelines or permanent standards for the small processor category. The ELG's being targeted are simple abattoir, complex abattoir, meat cutter, sausage and luncheon meat processor, ham processor, canned meat processor, and renderer.

For regulatory treatments of wastewater, various options are (US-EPA, 2002):

BAT2: DAF for fats separation, lagoon, disinfection (fat, BOD, TSS and pathogen removal), and nitrification (NH_3 removal).
BAT3: BAT2 + denitrification (nitrate removal).
BAT4: BAT3 + phosphorus removal.
PSESI (pre-treatment standards for existing sources): DAF, equalization (fat and TSS removal) and phosphorus removal.

Treatment technologies:

Primary: Screens and physical settling of heavy solids.
Advanced primary: Removal of pollutants with doses of chemical coagulants (metal salts or organic polyelectrolytes).
Secondary: Biological processes to decompose organic materials through activated sludge and waste stabilization ponds, and trickling filters.
Advanced secondary: Enhanced with either chemical coagulation or additional biological processes to increase the removal efficiency of solids, BOD and nutrients.
Tertiary or advanced treatment: For very high-removal efficiency with high-dosage chemical

Table 4
Abattoir wastewater treatment results

Treatment	Organic loading rate (OLR)	Temperature (°C)	HRT	BOD reduction (%)	COD reduction (%)	TSS reduction	References
Primary							
Screen, DAF					68	62%	Massé and Massé (2000a)
Chemical, DAF					42	48%	Massé and Massé (2000a)
Anaerobic							
Anaerobic lagoon	1600–4800 mg/L		13 d	87		81%	Massé and Massé (2000a)
Anaerobic lagoon	1.6–3.2 kg BOD/m^3/d		12–14 d	97	96	95%	US-EPA (2002) and Johns (1995)
AFR	3–10 kg/m^3/d	36			70–90		Metzner and Temper (1990)
AFR	2–3 kg/m^3/d	33			80–85		US-EPA (2002)
EGSB	15 kg COD/m^3/d	35	5 h		65–80	6 kg/m^3/d	Nunez et al. (1999)
UASB	11 kg COD/m^3/d	30	12–14 h		55–85		Sayed et al. (1987)
UASB	7 kg COD/m^3/d	20	11–45 d		82		Sayed et al. (1987)
UASB	5300 mg COD/L		5.2–15.6 d		72–87		Hansen and West (1992)
UASB			14–22 h	95	77–91	81–86%	Caixeta et al. (2002)
Flocculent UASB	6.5 kg COD/m^3/d		1.2 d		60–90		Ruiz et al. (1997)
Flocculent UASB	1.4 kg COD/m^3/d		0.5 d		80		Campos et al. (1986)
Two stage UASB	15 COD/m^3/d	18/30	0.2 d		90		Sayed et al. (1993)
Integrated UASBAF	5–32 COD/m^3/d		0.1–0.5 d		45–98		Borja et al. (1995b)
Anaerobic filter (AF)	2–18.5 COD/m^3/d		0.5–5 d		30–85		Tritt (1992)
Anaerobic filter (AF)	5 COD/m^3/d		1.5 d		63–85		Ruiz et al. (1997)
AFFR	8–35 kg COD/m^3/d				85–95		del Pozo et al. (2000)
ASBR	2.25–2.86 kg/m^3/d	20–25			90		Massé et al. (2001)
Fluidized bed AFB	35 COD/m^3/d		0.1–0.3 d		85		Borja et al. (1995a)
Aerobic							
Aerobic lagoon			3–10 d	95		Poor	US-EPA (2002)
Trickling filter				60–90			US-EPA (2002)
Activated sludge	0.4–8 kg BOD/m^3/d			95		95%	US-EPA (2002)
FBBR	305–602 mg BOD/L	25	8.8–30.8 min	71–93		62–73%	Li et al. (1986)

HRT = Hydraulic retention time, EGSB = Expanded granular sludge bed reactor, AFR = Anaerobic filter reactor, UASB = Up-flow anaerobic sludge blanket, ASBR = Anaerobic sequencing batch reactor, AFFR = Anaerobic fixed film reactor, FBBR = Fluidized bed biofilm reactor, AF = Anaerobic filter, DAF = dissolved air floatation, and AFB = Anaerobic fluidized bed.

Table 5
Parameters for pathogen inactivation in biosolids (compiled from US-EPA, 2002; Reimers et al., 1999; Rohwer, 1984; Yang, 1996)

Biosolids disinfection process	Irradiation	Temperature	Solids content	NH	Organic by-products	Dessicants
Composting	–	+	–	±	+	–
Anaerobic digestion	–	+	+	–	+	–
Aerobic digestion	–	+	+	–	–	–
Lagoon storage	–	+	+	–	+	–
Air drying	+	+	+	–	–	+
Alkaline stabilization	–	+	+	+	–	+
Irradiation	+	–	–	–	–	–

(+): The effect of the parameters in the column heads is to increase the rate or extent of inactivation in the process in column 1.
(–): The effect of these parameters do not influence the inactivation process.

Table 6
Distribution of wastewater treatment units in MPP industry (adapted from US-EPA, 2002)

Treatment category	Treatment unit	Percent of direct/indirect discharging facilities having the treatment unit in place	
		Direct discharger	Indirect discharger
Primary treatment	Screen	98	64
	Oil and grease removal	83	77
	Dissolved air floatation	81	46
	Flow equalization	75	34
Secondary and tertiary treatment	Biological treatment[a]	100	13
	Filtration	23	0
	Disinfection	92	0

[a] Biological treatment includes any combination of the following: aerobic lagoon, anaerobic lagoon, facultative lagoon, any activated sludge process, and/or other biological treatment processes (e.g. trickling filter).

Table 7
Proposed technology options for the MPP industry (adapted from US-EPA, 2002)

Treatment units	Technology options								
	Direct discharger					Indirect discharger			
	1	2	3	4	5	1	2	3	4
Screen	x	x	X	x	x	x	x	X	x
Dissolved air flotation (DAF)	x	x	X	x	x	x	x	X	x
Equalization tank						x	x	X	x
Anaerobic lagoon	x	x	X	x	x				
Biological treatment with nitrification	x[a]	x	X	x	x		x	X	x
Biological treatment with nitrification and denitrification			X	x	x			X	x
Biological treatment with nitrification and denitrification and phosphorous removal				x	x				x
Filter					x				
Ultraviolet (UV) disinfection	x	x	X	x	x				

(x): Treatment unit is required for that option, EPA only considered direct option 5 for poultry facilities only.
[a] Direct option 1 uses a less optimized form of nitrification.

coagulation, biological processes for nitrification and denitrification, filtration, and adsorption with granular activated carbon or reverse osmosis.

Proposed technology options for the MPP industry are included in Table 7. These are screening, DAF, equalization, aerobic lagoon, biological treatment with nitrification or with nitrification and dinitrification, filtering and UV disinfection. Improvements in wastewater reduction and BOD reduction with the use of BAT for pig and cattle abattoirs are summarized in Table 8. Table 9 provides summary of technologies for proposed options for MPP industry.

6.1. Cost of treatment

In 1995–96, overall treatment cost varied from Can$0.70 to $1.60 per m^3 of wastewater, with the exception of one plant which paid Can$5/$m^3$ (Massé and Massé, 2000a). The sludge (with residue) was landspread after mixing with compost. The wastewater did not include the water discharged from scalding tank.

Table 8
Benchmarks for pig (90 kg) and cattle abattoirs (250 kg) (adapted from COWI, 1999)

	Traditional technology	Average technology	Best available technology
Pig			
Water, L/animal	1400	700	300
Heat and electricity, kW h/animal	125	50	30
BOD_5, g/animal	2500	1000	500
Cattle			
Water, L/animal	5000	2500	1000
Heat and electricity, kW h/animal	300	125	70
BOD_5, g/animal	5500	2500	1200

Table 9
Summary of technologies for proposed options for MPP facilities (adapted from US-EPA, 2002)

Subcategory	Regulatory level	Technology option	Technical components
(A) Simple abattoir (B) Complex abattoir	BPT	2	Equalization, dissolved air flotation, secondary biological treatment with nitrification
(C) Low-processing packaging (D) High-processing packaging	BAT; NSPS	3	Equalization, dissolved air flotation, secondary biological treatment with nitrification and denitrification
(F) Meat cutter (G) Sausage and luncheon meats processor	BPT	2	Equalization, dissolved air flotation, secondary biological treatment with nitrification
(H) Ham processor (I) Canned meat processor	BAT; NSPS	3	Equalization, dissolved air flotation, secondary biological treatment with nitrification and denitrification
(J) Renderer	BPT; BCT	2	Equalization, dissolved air flotation, secondary biological treatment with nitrification
	BAT; NSPS	2	Equalization, dissolved air flotation, secondary biological treatment with nitrification
(K) Poultry first processing (facilities which slaughter up to 10 million lb/yr)	BPT; BCT	1	Equalization, dissolved air flotation, secondary biological treatment with less efficient nitrification
(L) Poultry further processing (facilities which produce up to 7000 lb/yr of finished product)	BAT; NSPS	1	Equalization, dissolved air flotation, secondary biological treatment with less efficient nitrification
(K) Poultry first processing (facilities which slaughter up to 10 million lb/yr)	BPT; BCT	3	Equalization, dissolved air flotation, secondary biological treatment with nitrification and denitrification
(L) Poultry further processing (facilities which produce up to 7000 lb/yr of finished product)	BAT; NSPS	3	Equalization, dissolved air flotation, secondary biological treatment with nitrification and denitrification

Quebec (Canada) has initiated upgrading of established and new abattoirs under "Programme Modernization of Abattoirs". Provincial funding is being allocated to finance plans, renovations, enlargements and equipment to modernize facilities and will cover up 50% of costs and up to Can$200,000 for single applicants, or up to Can$400,000 for joint ventures. Funding also covers on-site treatment initiatives.

Cornell Waste Management Institute Fact Sheet (2002), reported that abattoirs and livestock farmers are finding themselves, in many cases, without disposal services or facing high-disposal fees. The US butchers are paying upwards of US$20/barrel or US$30–40/steer for residual disposal. Total cost to the slaughter industry for beef slaughter residuals alone would be approximately US$10 million for disposal of 58,000 tons of waste. Total biosolids generated and management practices by number and percentage of total biosolids generated are listed in Tables 10 and 11. The practices used are composting, lime stabilization, drying, land filling, incineration, surface disposal, lagoon storage and others.

7. Treatments to reduce microbial load

Temperature and pH are two factors that determine the pathogen content (Jones, 1999). Treatment of solids and sludge with temperatures greater than 45 °C (composting, heat treatment, and thermophilic digestion) can reduced the pathogens to non-detectable levels. Inactivation rates of organisms were found to double with a 10 °C rise in temperature and to increase with decrease in soil moisture (Reddy et al., 1981). Pathogen inactivation using various primary and secondary treatments of abattoir wastewater and other disinfection treatments are provided in Tables 12–15.

Table 10
Total biosolids generated and management practices by % of total generated (adapted from Goldstein, 2000)

State	Total WWTP	Land application	Composting	Lime stabilization	Heat drying or pelletization	Land filling	Incineration	Surface disposal	Lagoon storage	Other
AL	47,000	59	1	1	1	25	1	0	0	12
AK	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
AZ	50,000	90	1.5	0	0.5	4	0	4	0	0
AR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CA	700,000	56	13	1	0	20	3	4	1	2
CO	85,000	91	<1	0	0	3	0	0	6	0
CT	84,000	0	3	0	0	4	93	0	0	0
DE	21,000	18	1	80	0	>1	0	0	0	0
FL	270,000	66	3	20–25	3	17	8	0	0	3
GA	175,000	25	3	0	3	43	24	0	0	2
HA	17,000	0	17	0	0	83	0	0	0	0
ID	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
IL	390,000	41	<1	0	0	11	0	36	10	2
IN	60,000	95	5	<1	0	0	0	0	0	0
IA	50,000	95	2	0	0	0	3	0	0	0
KS	n/a	50	15	5	0	40	10	0	0	0
KY	65,000	18	3	3	0	76	0	0	0	0
LA	n/a	30	3	0	1	34	15	10	0	5
ME	25,000	44	48	0	0	8	0	0	n/a	>1
MD	151,000	41	6	0	6	5	3	0	n/a	39
MA	269,000	1	7	1	12	20	54	0	0	5
MI	260,000	32	0	n/a	0	34	34	0	0	0
MN	265,000	21	0	0	0	19	60	0	0	0
MS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
MO	227,000	31	1	0	0	1	54	7	0	6
MT	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NV	38,500	15	5	0	0	80	0	0	0	0
NH	18,000	11	20	0	0	47	22	0	0	0
NJ	232,000	4	11	24	4	0	26	0	0	31
NM	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NY	360,000	1	6	3	1	11	30	0	0	48
NC	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ND	4810	20	0	0	0	80	0	0	0	0
OH	400,000	54	n/a	n/a	0	9	30	0	n/a	7
OK	70,000	75	1	35	0	25	0	0	0	0
OR	50,000	99	2	11	0	<1	0	0	0	0
PA	307,000	42	10	7	1	38	14	0	n/a	6
RI	28,000	0	8	0	0	4	88	0	0	0
SC	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SD	20,000	73	0	0	0	19	0	8	0	0
TN	n/a	70	2	2	0	10	0	6	10	0
TX	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
UT	49,000	53	27	0	0	4	0	16	0	0
VT	7000	25	50	0	0	20	5	0	0	0
VA	225,000	54	6	n/a	0	10	30	0	0	0
WA	75,000	85	n/a	n/a	n/a	5	10	n/a	0	n/a
WV	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WI	37,000	80	0	n/a	n/a	10	10	0	0	0
WY	3600	95	0	0	0	0	0	5	0	0
Total	5,135,910	40.10%	5.40%	4.10%	1.40%	17.20%	21.90%	3.80%	0.90%	7.80%

WWTP = Wastewater treatment plants.

The pH range can effectively inhibit the growth of microorganisms. Most pathogens including *E. coli* and *Salmonella* tend to survive better in a pH range of 6–7 and are intolerant of acidic soil conditions. The pH can be adjusted with the addition of lime. To reduce the risk of bacterial contamination, quick-lime may be added (Vasseur et al., 1998). Six months storage at pH, not less than 11.5 is able to produce sanitized sludge (Gantzer et al., 2001).

Effective treatment of meat plant wastewaters can reduce these pathogens considerably. Meat plant wastewaters fall under Class B biosolids from the US Code of

Table 11
State biosolids management practices by number of facilities (adapted from Goldstein, 2000)

State	Total WWTP	Land application	Composting	Lime stabilization	Heat drying or pelletization	Land filling	Incineration	Surface disposal	Lagoon storage	Other
AL	268	44	2	3	1	54	5	0	0	12
AK	70	8	2	3	0	58	2	5	7	0
AZ	38	20	2	0	1	7	0	4	0	4
AR (1999)	350	52	5	1	3	42	0	0	0	247
CA	239	90	43	1	1	69	5	10	20	23
CO	450	85	20	2	2	7	0	2	10	n/a
CT	84	0	2	0	0	3	79	0	0	0
DE	29	7	1	2	0	1	0	0	0	0
FL	2681	1300	5	n/a	2	150	1	0	0	1200
GA	503	73	13	0	2	244	7	0	0	162
HA	34	0	6	0	0	28	0	0	0	0
ID	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
IL	476	436	1	n/a	0	61	0	3	42	17
IN	241	228	8	5	0	0	0	0	0	0
IA	76	73	1	0	0	0	2	0	0	0
KS	150	100	3	3	0	50	1	0	0	0
KY	251	42	4	3	0	202	0	0	0	0
LA	255	30	3	0	0	<200	1	20	0	0
ME	100	59	40	59	0	10	0	0	36	2
MD	300	53	6	22	3	62	4	0	56	112
MA	118	1	18	1	1	15	20	0	0	62
MI	185	169	0	n/a	0	6	12	0	0	1
MN	240	240	0	0	1	1	3	0	0	0
MS	335	19	0	0	7	10	0	20	0	279
MO	351	239	3	0	0	3	14	17	0	78
MT (1999)	300	12	4	0	0	5	0	3	0	n/a
NV	20	1	2	0	0	10	0	0	0	n/a
NH	79	22	12	10	0	18	1	0	38	0
NJ	326	22	46	4	5	0	150	0	0	47
NM	48	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NY	584	78	67	22	14	246	114	0	26	109
NC (1999)	342	117	39	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ND	290	2	0	n/a	n/a	1	n/a	n/a	0	n/a
OH	1500	358	6	18	0	97	11	0	n/a	25
OK	1150	100	2	5	0	100	0	0	0	n/a
OR	217	216	4	24	0	1	0	0	n/a	0
PA	790	115	7	23	1	84	15	1	n/a	n/a
RI	19	0	2	0	0	4	16	0	0	0
SC (1999)	102	36	6	5	2	51	1	1	0	n/a
SD	287	15	n/a	n/a	n/a	3	n/a	2	0	n/a
TN	277	99	3	4	0	53	0	17	101	n/a
TX (1999)	2500	1350	10	n/a	2	600	0	10	0	400
UT	27	24	14	1	0	1	0	1	1	n/a
VT	92	25	22	0	0	12	11	0	n/a	1
VA	93	41	5	2	0	33	11	0	n/a	0
WA	345	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WV	–	–	–	–	–	–	–	–	–	–
WI	485	477	0	n/a	n/a	11	2	0	0	n/a
WY	10	9	0	0	0	0	0	1	0	0
Total	17,707	6487	439	223	48	2413	488	117	337	2781
		36.64%	2.48%	1.26%	0.28%	13.63%	2.76%	0.66%	1.90%	15.71%

(–): Indicates that no information is available.
WWTP = Wastewater treatment plants.

Federal Regulations (40 CPR) Part 503 rules. Class B biosolids are typically treated using a “Process to Significantly Reduce Pathogens” (PSRP) such as aerobic digestion, anaerobic digestion, air drying, and lime stabilization. When Class B requirements are met, the level of pathogenic organisms is significantly reduced, but pathogens are still present. In this case, other precautionary measures required by the Part 503 rule, i.e. site and crop harvesting restrictions, are implemented for the protection of public health.

Table 12
Pathogen removals by various wastewater treatment processes (Ontario data) (adapted from US-EPA, 2000)

Process	Percent removed			
	Bacteria (%)	Enteric viruses (%)	Protozoan cysts (%)	Helminth eggs (%)
Primary sedimentation	50–90	0–3	10–90	30–90
Trickling filter[a]	90–95	90–95	50–90	50–95
Activated sludge	90–99	90–99	50	50–99
Oxidation ditch	90–99	90–99	50	50–99
Stabilization pond[b]	99.99–100	99.99–100	100	100

[a] With primary sedimentation and recycle streams from digestion and drying.

[b] Three ponds in series with more than 25-day hydraulic retention time.

Table 13
Process criteria for class B (adapted from NRC, 2002 from EPA, 2001)

Process	Temperature, °C	Critical parameter	Time	Possible measure of efficiency
Air drying	>0	Desiccation by-products	2–3 mo	*E. coli*, faecal coliform, *Clostridium perfringens*
Alkaline stabilization	Ambient	Ammonia, pH	2 h	*Clostridium perfringens*
Aerobic digestion	15–20	Endogenous microbial activity	60–40 d	Faecal coliform, *E. coli*
Anaerobic digestion	20–35	Endogenous microbial activity, organic by-products	60–15 d	*Clostridium perfringens*
Composting	40–55	Organic by-products	5 d at 40 °C 4 h at 55 °C	*Clostridium perfringens*

Table 14
Class B virus reduction for biosolids disinfection process (compiled from NRC, 2002; EPA, 2001)

Process	Virus log reduction	Time
Lagoon storage	1–2	6–12 mo
Mesophilic anaerobic digestion	1–2	15–30 d
Mesophilic aerobic digestion	1–2	15–30 d
Alkaline stabilization, pH = 11–12	1–3	1 d
Air drying <3% solids	<1	2–3 mo
Air drying >3% solids	3–4	2–3 mo
Heat drying 55–60 °C	3–4	~1 h
Composting 40–55 °C	3–4	6 week

7.1. Disinfection

Pathogens from wastewater are destroyed using chlorine, UV and/or ozone. Microbial level, and potential for growth in wash water can also be reduced by adding bactericide such as an organic acid (2–3% concentration of acetic or lactic acid) or potassium chloride. High-intensity UV lamps or ozone treatment can reduce microbial load online in wastewater without increasing temperature, and water can be reused. The risk of pathogen infection associated with wastewater application on agricultural field depends on the effectiveness of treatments in inactivating or removing pathogens, pathogen survival in soil, crops, runoff and ground water. Treating wastewater by irradiation is feasible in inactivating pathogens because the radiation penetrates the wastewater and may induce fundamental changes. Suspensions of ova extracted from abattoir sludge were disinfected using an electron beam accelerator. Decimal microbial reduction time (D_{10}) values were 788 ± 72 Gy for suspensions of ova (Capizzi-Banas and Schwartzbrod, 2001).

Microorganisms can also be inactivated by (i) heat, (ii) chemicals—chlorine, acids, and phosphates, (iii) Radiation—irradiated with high-speed electrons (β rays) or with X-rays (or γ rays), (iv) electronic pasteurization—electron beam accelerators: applied directly with electrons or optimizing the conversion of electron energy

Table 15
Class A inactivation of pathogens (compiled from NRC, 2002; Reimers et al., 1986a, 1986b, 1999, 2001; EPA, 2001)

Process	Inactivation	Concerns
Aerobic digestion (thermophilic)	Time, temperature	Oxygen transfer, solids content, bioaerosols
Anaerobic digestion (thermophilic)	By-products, time, temperature	Solids content, odour, bioaerosols, pH
Composting (thermophilic)	By-products, time, temperature	Solids content, odour, bioaerosols, pH
Alkaline stabilization, Drying (>80 °C)	Ammonia, time-temperature Time-temperature	Solids content, odour, aerosols, pH, explosions, odours, aerosols
Irradiation (gamma, beta)	>1 megarad	Solids content, stabilization
Digester	Time-temperature, by-products	Solids content, odours, bioaerosols

to X-rays; the depth of penetration is less than 5 cm; an accelerator provides energy to electrons by providing an electric field to accelerate the electrons, and (v) pulsed light: only surface decontamination. Thermal processing can be safely used to produce pathogen-free sludge from sewage sludge or sludge from abattoir waste. For this, many time-temperature combinations can be applied such as 55 °C for 2 h when pH is greater than 12, or 55 °C for 4 h during a thermophilic stabilization process or during a composting process (EPA, 2001). Beta ray irradiation: pathogens in wastewater or sludge can be destroyed by β-rays irradiation using an accelerator at dosages of at least 1.0 megarad at 20 °C (US-EPA, 2003). Gamma ray irradiation: pathogens can also be destroyed by γ-rays irradiation using certain isotopes such as 60 Cobalt and 137 Cesium at dosages of at least 1.0 megarad at 20 °C (US-EPA, 2003).

8. Wastewater reduction recommendations

After implementing water conservation program in a hog slaughtering and rendering plant, 33% wastewater was reduced (Carawan and Clemens, 1994) in the USA. In a poultry processing operation, clean-up wastewater was reduced from 20% to 50% after initially dry cleaning processing areas and equipment (Gelman et al., 1989). Wastewater consumption can also be reduced by conversion to high-pressure, low-volume systems for carcass washing and general sanitation. In poultry processing, wastewater can also be reduced by multiple use of water in various processes. Examples are (i) use of scalder overflow to flume feathers from mechanical de-feathering equipment, and (ii) the use of chiller overflow to flume inedible viscera to screens for recovery prior to rendering (Witherow et al., 1978).

Wastewater in abattoirs can be reduced by treatment of immersion chiller effluent by membrane filtration which can produce recyclable water. Total organic C can be reduced below 100 mg/L, and bacteria cannot pass through the membrane pores. The followings are some recommendations for specific pollution control identified by US-EPA (2002): (i) Provide sufficient bleed time and confine bleeding. (ii) Use minimum water quantity in the scalder and chillers as approved by USDA. (iii) Reuse chiller water as makeup water for the scalder. (iv) Use steam in place of water for hog scalding. Large water and wastewater can be saved by using steam instead of hot water in hog scalding. (v) Floors and tables should be dry-cleaned prior to wash down to reduce wastewater. (vi) High-pressure and low-volume spray nozzles or steam-augmented systems should be used for plant wash down. (vii) Wastewater from thawing operations can be reduced.

Other remedies to reduce waste and wastewater from abattoirs are: some modifications in the plant will (i) reduce wastewater, (ii) reduce and/or prevent product loss to sewers, and (iii) reuse wastewater. Process design to reduce wastewater includes: large use of water for cleaning purposes creates excessive amounts of wastewater production. Solids and organic material collection before wet cleaning can reduce BOD/COD level. For this, vacuum cleaning of the kill floor will reduce BOD loadings. Other remedies are (Dencker et al., 2002): (i) Redesign of spray nozzles and other water distribution mechanisms will minimize wastewater and washing of soluble BOD down the drains. (ii) Squeeze-to-open valves can minimize excessive use of water. Recycling wastewater within the plant should be considered. Water from a vapour phase condenser can be used to sluice the hair in the de-hairing machine, manure drain, etc. (iii) Segregation: Blood should be collected separately, and blood drain should be connected to a blood recovery system; grease (fat) segregation and clear water segregation are important. (iv) Low-flow high-concentration line should be separated from high-flow low-concentration. Pretreatment of low-flow high-concentration lines will be beneficial. (v) Blood and solids should be dry collected for rendering. (vi) De-hairing machine: collect the hair dry. Use recycled water from final carcass washing or vapour phase trolley cleaning. (vii) Rail polisher: a micro-switch-operated solenoid valve should be installed to turn off water when no hog is in the rail polisher. (viii) Carcass shower: nozzle system should spray water only on the hogs and not between them. A switch-operated solenoid valve is needed to control water flow as above. (ix) Brisket-Breaking-Evisceration: dilute wastewater should be directed into drains and away from areas of scrap and blood clots. Blood clots and floor scrap should be vacuum cleaned to reduce pollution load. (x) Viscera pans and tread mill: wastewater can be reduced by installing more efficient cleaning nozzles. Timer-controlled solenoid valves should be installed to turn off water after production. (xi) Scraped fat areas: additional catch trays are useful.

The planning for abattoir waste minimization should incorporate the following options (EPA, 2000): (i) changing the processes or equipment, (ii) changing the composition, packaging or durability of products, (iii) changing or reducing raw material inputs, (iv) improving the control of the process, (v) improving the materials handling and cleaning operations, (vi) improving the maintenance and repair of equipment, and (vii) recycling waste internally, re-using waste on site.

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