DAIRY CATTLE MORTALITY MANAGEMENT VIA ANAEROBIC DIGESTION

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INTRODUCTION

With the decline in the number of rendering operations due to industry consolidation and concern about Bovine Spongiform Encephalopathy (BSE) transmission, disposal of dairy and beef cattle mortalities by rendering either is not an option or is prohibitively expensive in many areas of the United States. On-site burial remains an alternative in many states, but impact on ground water quality is of concern. Many landfill operators either refuse to accept livestock mortalities for disposal, or the cost is difficult for producers to absorb. Incineration, an option for carcass disposal, has high investment and operating costs and is complicated by regulatory compliance issues. Another disposal alternative is co-composting with a carbonaceous material such as sawdust or straw. However, both incineration and composting generally are more suitable for the disposal of small animal mortalities such as those from poultry operations.

The success, especially in Europe, of using anaerobic digestion for the stabilization of slaughterhouse wastes suggests co-digestion of large animal mortalities with manure and possibly other wastes is a viable disposal option for dairy cattle, beef cattle, and swine mortalities. To evaluate the feasibility of this approach for dairy cattle mortality disposal, we began by estimating methane production potential. Our approach was based on typical dairy cow carcass composition and a validated mathematical model that translates carcass composition into methane production potential. We also evaluated the risk of BSE and Johne's disease transmission via digester effluent.

DAIRY CATTLE CARCASS COMPOSITION

Andrews *et al.* (1994) determined the composition of mature Holstein cows at three physiological stages: prepartum (dry), early lactation, and late lactation. Based on their findings, we calculated average Holstein carcass composition based on the prepartum, early lactation, and late lactation values listed in Table 1. These values include gastro-intestinal tract contents and embryos. We assumed that: 1) the mass of non-protein nitrogen present is negligible, and 2) the mass of carbohydrates present can be estimated as the difference between total volatile matter and the sum of protein and fat.

METHANE PRODUCTION POTENTIAL BASED ON GROSS ENERGY

As shown in Table 2, conversion of gross energy as kcal per kg live weight to specific methane yield as ft^3 per lb of volatile solids (VS) produces an average specific methane yield of 2.5 ft^3 per lb of VS. This is an unrealistically low value considering that the generally accepted specific methane yield for dairy cattle manure is about three to four ft^3 per lb of VS added.

Table 1. Mature Holstein carcass composition (after Andrews *et al*, 1994)

	Prepartum	Early Lactation	Late Lactation	Mean
Live weight, kg	584	555	556	565
Moisture, kg	274	299	289	287
Dry matter, kg	310	256	267	278
Volatile solids (VS), kg	289	232	243	255
Ash, kg	22	23	24	23
Protein, kg[a]	78	81	86	82
Protein, % of VS	42.2	48.2	49.3	46.6
Fat, kg	90	48	81	73
Fat, % of VS	38.1	25.4	37.4	33.6
Carbohydrates, kg[b]	121	104	77	100
Carbohydrates, % of VS	19.6	26.4	13.3	19.8
Gross energy, kcal/kg LW	2120	1620	2170	1970

[a]Calculated from total nitrogen by multiplying by 6.25
[b]Calculated as the difference between total volatile matter and the sum of protein and fat

Table 2. Estimate of carcass methane production potential based on gross energy

	Prepartum	Early Lactation	Late Lactation	Mean
Gross energy, kcal/kg LW	2120	1620	2170	1970
Gross energy, Btu/kg LW	534	408	547	496
Methane, ft^3/kg VS	0.56	0.43	0.57	0.52
Methane, ft^3/lb VS	2.50	2.23	2.85	2.53

METHANE PRODUCTION POTENTIAL BASED ON THEORETICAL CONSIDERATIONS

Buswell and Neave (1930) proposed that the theoretical methane production potential of specific organic compounds could be calculated as follows:

$$C_nH_aO_b + \left(n - \frac{a}{4} - \frac{b}{2}\right) x H_2O \rightarrow \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right) x CH_4 + \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right) x CO_2 \quad (1)$$

On this basis, Angelidaki and Sanders (2004) calculated the theoretical methane production potential of representative proteins, carbohydrates, and lipids per g of VS and the methane content of the biogas produced (Table 3). They noted that practical methane yield always would be lower because of the following factors:

- substrate utilized to synthesize microbial mass
- substrate lost in the effluent
- resistance of lignin to anaerobic microbial degradation
- binding in particulate matter
- nutrient limitations

Although some lignin will be present in the gastro-intestinal tract of dairy cow mortalities, it will be minimal and not significantly reduce carbohydrate biodegradability.

Table 3. Theoretical methane production potential of carbohydrates, proteins, and lipids(Angelidaki and Sanders (2004).

Substrate	Composition	CH_4 yield, L/g VS	Biogas CH_4 content, %
Carbohydrates	$(C_6H_{10}O_5)_n$	0.415	50
Proteins[a]	$C_5H_7NO_2$	0.496	50
Lipids	$C_{57}H_{104}O_6$	1.014	70

[a]Nitrogen is converted to NH_3.

Based on the work of Angelidaki and Sanders (2008), Hejnfelt and Angelidaki (2009) proposed that theoretical methane yield from slaughterhouse wastes could be calculated based on the relative fractions of proteins, lipids, and carbohydrates as follows:

$$CH_4,\ m^3/kg\ VS = (0.496X) + (1.014Y) + (0.415Z) \quad (2)$$

where: X = protein fraction of VS, decimal
Y = lipid fraction of VS, decimal
Z = carbohydrate fraction of VS, decimal

As shown in Table 1, Andrews *et al.* (1994) data suggest that the VS in an average mature Holstein carcass are 46.6 percent protein, 33.6 percent fat, and 19.8 percent carbohydrates. Substituting these values into Equation 2 yields a theoretical methane yield of 0.654 m^3 per kg of VS (10.5 ft^3 per lb of VS) for dairy cow mortalities. This translates into approximately 3,000 ft^3 of methane per 1,400 lb cow.

EXPERIMENTAL RESULTS

In their study of the anaerobic digestion of swine slaughterhouse wastes, Hejnfelt and Angelidaki (2009) reported that a mixture of solid wastes with blood produced a maximum rate of 0.620 m^3 of methane per kg of VS added (9.9 ft^3 per lb of VS added) in a series of 40-day, mesophilic batch studies. This maximum rate occurred at a waste-loading rate of five percent by volume. Waste loading rates of 20, 50, and 80 percent decreased methane yield. The theoretical methane yield for this waste was calculated using Equation 2 to be 0.600 m^3 per kg of VS added (9.6 ft^3 per lb of VS added). Neither thermal pretreatment nor pretreatment by the addition of sodium hydroxide had a significant effect on the biodegradability or methane yield of the mixed pork waste.

In a continuously stirred tank reactor experiment at 37 °C in which mixed pork wastes were co-digested with swine manure, the mixed pork loading rate of five percent by volume produced the highest specific methane yield from the pork waste of 0.900 m^3 per kg of VS added (14.4 ft^3 per lb VS added). Given that the specific methane yield for the pork waste was higher than the theoretical methane yield and the yield observed in the batch studies, Hejnfelt and Angelidaki suggested the possibility of a synergetic effect increasing the methane yield from the swine manure.

Hejnfelt and Angelidaki suggest that a high dilution rate, such as five percent, is preferable, and animal by-products may contain compounds that can inhibit methanogenesis. Specifically, they cite the work of Angelidaki *et al.* (1990), Angelidaki and Ahring (1992), and Broughton *et al.* (1998), which indicates that lipids could cause problems during anaerobic digestion because of the possible accumulation of intermediates, such as long-chain fatty acids inhibiting microbial activity. They also suggest that process stability is problematic with thermophilic digestion and probably is due to the inhibition of methane-forming bacteria by ammonia.

Massé *et al.* (2008) investigated the feasibility of co-digesting swine mortalities with swine manure in sequencing batch reactors at 20 and 25 °C as a method for on-farm carcass disposal. Sequencing batch reactor performance at loading rates of 20 and 40 kg of ground whole 130 kg carcasses per L of manure was determined for two and four week treatment cycles. At 25 °C, there were no statistically significant differences in methane production between the control reactors (only manure) and reactors that received a mixture of manure and 20 or 40 kg per L of ground carcasses per kg of chemical oxygen demand (COD) added. Methane production ranged from 0.274 to 0.334 m^3 of methane per kg of COD (approximately 0.702 to 0.856 m^3 of methane per kg of VS or 11.24 to 13.7 ft^3 per lb of VS) fed. Based on the composition of the carcasses used in this study, Equation 2 predicts a specific methane yield of 0.727 m^3 of methane per kg of VS added (11.6 ft^3 per lb of VS added).

Massé *et al.* (2008) also mentioned the inhibitory effect of long-chain fatty acid accumulation and cited the work of Chen and Shyu (1998) exploring the feasibility of anaerobically digesting poultry mortalities. Chen and Shyu found methane formation was inhibited even at the low loading rate of 2 g COD per L of reactor volume per day. Massé *et al.* also cited the work of Abraham *et al.* (2006), which indicated that total fatty acids accumulated and pH decreased when the ratio of lipids to proteins exceeded 0.1.

BIOSECURITY ISSUES

Acceptance of anaerobic digestion as a method of dairy cattle mortality disposal will depend on the perception of the risk for transmission of BSE and Johne's disease in digester effluent. BSE is a progressive, fatal, neurologic disease of adult domestic cattle that is similar to scapie in sheep and goats (Merck and Company, Inc., 1998). Johne's disease, also known as paratuberculosis, is chronic, contagious enteritis characterized by persistent and progressive diarrhea, weight loss, debilitation, and eventually death (Merck and Company, Inc., 1998).

Incidence of BSE has been linked to the inclusion of bovine derived meat and bone meal in cattle rations. In response to this finding, the feeding of rendering products that contain or may contain protein derived from mammalian tissues to cattle or other ruminants has been prohibited in the United States since May 1997 (Federal Register, 1997). Canada, the European Union, and the United Kingdom have similar regulations in effect.

Through February 2011, surveillance has identified 22 cases of BSE in North America of which three were in the United States and 19 in Canada (CDC, 2011). Of the three cases in the United States, one animal was born in Canada. The first known case of BSE in the United States was identified in 2003. These data suggest that the probability is extremely low that a dairy cattle mortality received for disposal by anaerobic digestion with manure contains the prion responsible for BSE. In addition, the Peer Review of the Estimation of BSE Prevalence in the United States (Patil, 2006) supported the U.S. Department of Agriculture Animal and Plant Health Inspection Service's estimated prevalence of BSE of only 1 in 1,000,000 live cattle in the United States.

This information suggests that the risk of the presence of the prion responsible for BSE in dairy cattle mortalities received for disposal by anaerobic digestion is highly unlikely. In addition, transmission to man or other animals only can occur by ingestion of infected tissue. However, removal of brain and spinal column tissue before mortality maceration prior to anaerobic digestion would be an option, although removal would be a manual process.

The causative agent of Johne's disease is *Mycobacterium avium paratuberculosis*, which is present in the feces of infected animals and is transmitted by ingestion of fecal material. Given the prevalence of Johne's disease in U.S. dairy cattle, it is unlikely that co-digesting dairy cattle mortalities with manure will exacerbate this problem. Conversely, some mitigation in the risk of transmission may be realized. Martin *et al.* (2003) reported an average of a two $\log_{10}$ (99 percent) reduction in the density of *M. avium paratuberculosis* during the anaerobic digestion of dairy cattle manure in a plug-flow digester at 35 °C.

INFRASTRUCTURE REQUIREMENTS

Prior to anaerobic digestion, dairy cattle mortalities will have to be macerated to maximize decomposition and avoid clogging of pumps, etc. Two sources of apparently suitable equipment are Supreme International Limited of Wetaskiwin, Alberta, Canada and Karl Schnell, Inc., New London, WI, the U.S. distributor for Karl Schnell GmbH and Company of Winterbach, Germany. Supreme International manufactures feed processing equipment as well as equipment for cutting and blending a variety of organic wastes including cattle mortalities. Karl Schnell GmbH primarily is a manufacturer of equipment for the food processing industry.

Mortality processing should be performed in an enclosed facility with a receiving and a processing area and the appropriate equipment for the transfer of the carcasses from the receiving area into the macerating unit. The addition of manure to the maceration unit will be necessary manure to facilitate the production of slurry that can be transferred by gravity or pumping. Ideally, the mortality processing facility should be located near the digester influent storage tank that will receive the macerated mortalities. This will facilitate transfer by gravity.

ECONOMIC FEASIBILITY

Because of the substantial cost of the required maceration equipment and the other infrastructure requirements, we believe that on-site disposal of dairy cattle mortalities by anaerobic digestion is suitable only for very large operations. Our research suggests that the cost of a suitable maceration unit will be at least $50,000 and could be as much as $250,000, depending on the manufacturer. For smaller operations, delivery of mortalities to a centralized anaerobic digestion operation, or use of a portable maceration unit owned cooperatively or by a third party could be options.

SUMMARY

Both theoretical considerations and experimental results suggest that anaerobic digestion with a suitable co-substrate such as manure is a technically feasible option for the disposal of dairy as well as other large animal mortalities. However, economic feasibility will depend on site-specific variables such as the monetary value of the additional methane produced and the cost of available alternatives for mortality disposal.

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