Anaerobic Digestion as a Treatment Strategy to Enable Resource Recovery in Intensive Food Production

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Intensive food production industries such as slaughterhouses are strong candidates for treatment processes aimed at recovery of both energy and nutrient resources. However, there is limited information available, particularly on the separate streams available and the contribution to effluent loads. This study reports biochemical and chemical analysis to identify the concentration and accessibility of energy and nutrients, within individual wastewater streams from major processing areas in a range of Australian slaughterhouses, with more detailed results from a specific instance. The objective of this approach was to separate streams and design individual treatment processes to improve economic recovery of energy and nutrients. Bulk organic loads were 2-4 times greater than loads previously reported in literature with individual wastewater sources ranging from low strength (boning) to very high strength (rendering) with TCOD over 40,000 mg/L. There were also large differences in the concentrations of key nutrients N, P and K. Rendering and paunch wastewater were concentrated resource streams that contribute approximately 75% of the methane potential, phosphorus and potassium loads in only 20% of the volumetric flow. Anaerobic biodegradability and methane potential of all wastewater samples tested was high, confirming anaerobic digestion is a suitable approach to recover energy and release nutrients. Variations in the strength of different wastewater sources and management practices between sites are now being investigated.

Keywords: Anaerobic digestion, BMP, Slaughterhouse, Resource Recovery, Phosphorus

INTRODUCTION

Intensive food production industries such as beef slaughterhouses generate large volumes of wastewater rich in organic contaminants and nutrients (Johns 1995, Mittal 2006, Liu and Haynes 2011), and are therefore strong candidates for treatment processes aimed at recovery of both energy and nutrient resources.

Typically, literature reports the characteristics of combined effluents from slaughterhouses to be high strength (>5000 mg/L COD) and considers treatment options of only this combined stream (Massé and Masse 2000; Mittal 2006; Cowan et al. 1992; Johns 1995; Tritt and Schuchardt 1992). However, wastewater originates from several major process operations at a slaughter house, including cattle preparation, slaughter and recovery and reprocessing of by-products (Liu and Haynes 2011). Johns (1995) highlights the variation in organic and nutrient concentrations within these individual streams varying from medium strength (1,000-3,000 mg/L COD) to high strength (5,000-10,000 mg/L COD).

Large variations in the composition and strength of wastewater from different processing areas impact treatment technology selection, and may provide opportunities to capture individual streams for more appropriate treatment. However, recent developments in the source of wastewater within beef slaughterhouses and wastewater management strategies have not been reported, and in particular, there is limited information on biological availability of both bulk wastewater, and individual streams. We are currently conducting wastewater analysis across 6 major Australian slaughter houses and this paper reports results from this analysis. The study includes biochemical and chemical testing to identify levels, form, and accessibility of energy, nutrients, and metals.

METHODOLOGY

This study has now investigated 3 red meat processing facilities in Australia, with ongoing analysis at 3 additional sites. However, only results from Site A, are presented in this outline manuscript, being representative of the other sites. At the time of sampling, the Site A was processing approximately 800 head of cattle per day. Wastewater and solid waste samples were collected at regular intervals from all processing streams during a 4 day sampling period.

Chemical Analyses were performed for organic matter including: total solids (TS), volatile solids (VS), chemical oxygen demand (COD), oil and grease (O&G); and nutrients including: total Kjeldahl nitrogen (TKN), total Kjeldahl phosphorus (TKP) and potassium. Analytical methods were as for Standard Methods (APHA, 1998).

Triplicate BMP tests were conducted in 160ml serum bottles (100ml working volume) based on methods described by Angelidaki et al. (2009). All BMP tests were conducted at 37°C, using a N_2 headspace. Methanogenic inoculum was collected from a full-scale anaerobic digester treating mixed primary and activated sludge in Brisbane, Australia. The inoculum to substrate ratio used in the tests was 2 (VS basis). Triplicate blanks were conducted to correct for background methane.

RESULTS AND DISCUSSION

There were 6 major processing areas identified at the plant analysed in this study; cattle yards, slaughter floor, offal processing, paunch, boning room, and rendering operations. The general structure of the wastewater collection and handling process at all sites is presented in Figure 1. This is representative of the other sites being assessed.

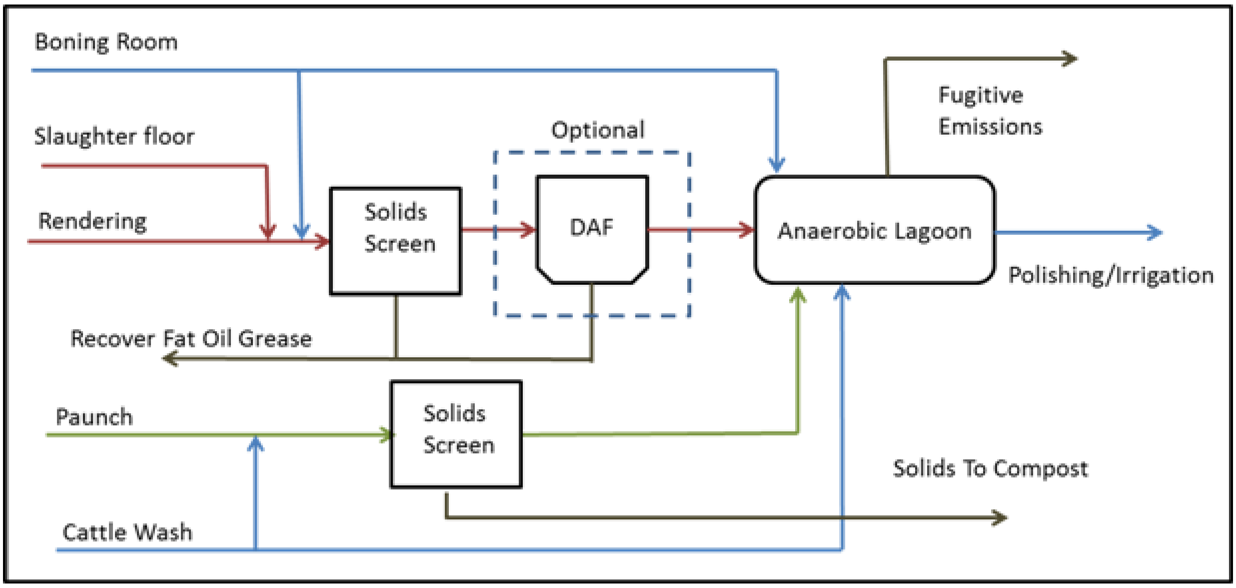

Figure 1: Major wastewater sources and structure of wastewater handling process at all sites.

A summary of wastewater compositions from Site A is shown in Table 1, overall water usage (not shown) and nutrient concentrations were within ranges expected from literature (Cowan et al. 1992; Johns 1995; Mittal 2004; Tritt and Schuchardt 1992). However organic strength (COD, TS, O&G) was substantially higher than literature, resulting in organic loads 2-4 times greater than loads previously reported (Cowan et al. 1992; Johns 1995; Mittal 2004; Tritt and Schuchardt 1992). Individual wastewater sources ranged from low strength (boning) to very high strength (rendering) with TCOD over 40,000 mg/L and there were also large differences in the concentrations of key nutrients N, P and K. Phosphorus was 2 to 4 times more concentrated in the rendering and paunch wastewater respectively compared to the final effluent. The concentration data suggests phosphorus recovery could be more effective and more economical if targeted towards individual wastewater streams.

Table 1: Concentration of organics and nutrients in slaughterhouse wastewater from Site A

Wastewater Source	TCOD mg/L	TS mg/L	O&G mg/L	N mgN/L	P mgP/L	K mgK/L
Cattle Yard	3,200	3,000	4	89	13	33
Slaughter Floor	3,800	3,500	210	2,020	28	27
Paunch Handling	23,900	15,800	2,600	520	211	175
Offal Processing	30,900	19,900	11,600	280	81	69
Boning Room	<100	-	-	-	-	-
Render Plant	40,000	24,600	5,500	1,700	120	483
Combined Effluent	12,900	8,400	2,300	245	58	75

Anaerobic biodegradability was evaluated as a platform to recover energy from the wastewater and release nutrients to facilitate resource recovery. Cumulative methane production curves (L CH_4 $kgVS^{-1}$) and a summary of B_0 values determined from parameter estimation are shown in Figure 2. Anaerobic biodegradability of all wastewater samples tested was high (0.8-1.0 on COD basis), with very low indications of inhibition or toxicity, suggesting a very good potential for anaerobic digestion, energy recovery, and release of nutrients. B_0 was highest in the offal and rendering streams and is consistent with the higher O&G content of this wastewater. The B_0 for paunch was higher than the B_0 expected for a lignocellulose based material (~400 L kgVS-1), and was likely due to O&G in this stream from intermittent mixing with offal processing wastewater.

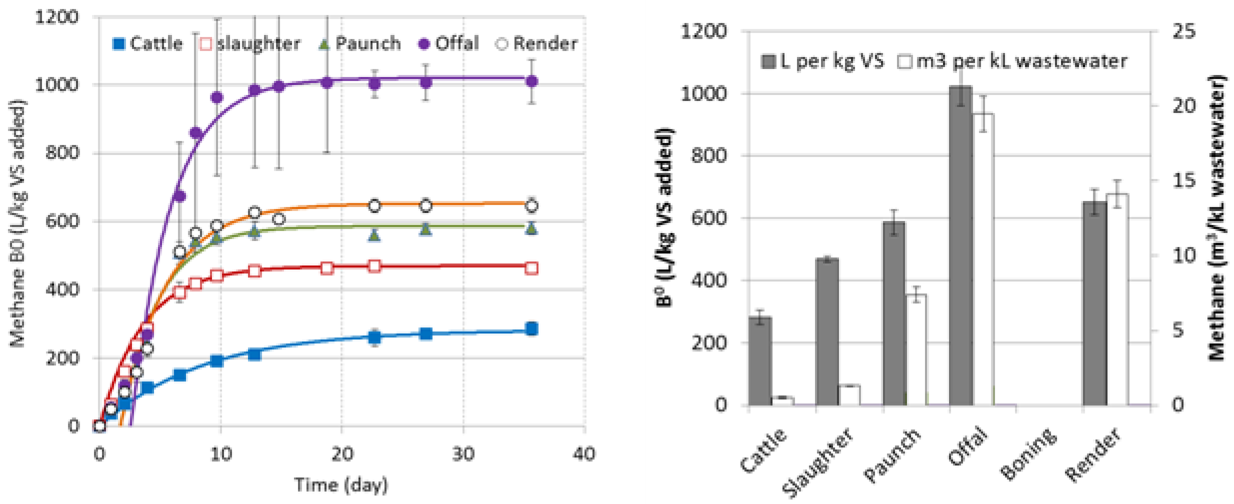

Figure 2: Cumulative methane production from BMP tests and summary of B_0 determined from first order model and parameter estimations.

The source of methane/energy potential and key nutrients from each processing area at Site A was evaluated from the composition and flowrate (data not shown) of each stream; the results are presented in Figure 3. Rendering and paunch wastewater are concentrated resource streams that contribute approximately 75% of the methane potential, phosphorus and potassium loads at Site A in only 20% of the volumetric flow. Slaughter floor wastewater contributed over 60% of the nitrogen load at Site A, this is a major increase compared to previous reports where the slaughter floor contributed less than 10% of N (Johns 1995) and may indicate changes in wastewater strategies over the past 17 years. Wastewater from the boning room and cattle yards were relatively large flows, but were low strength and contributed little to the energy and nutrient loads.

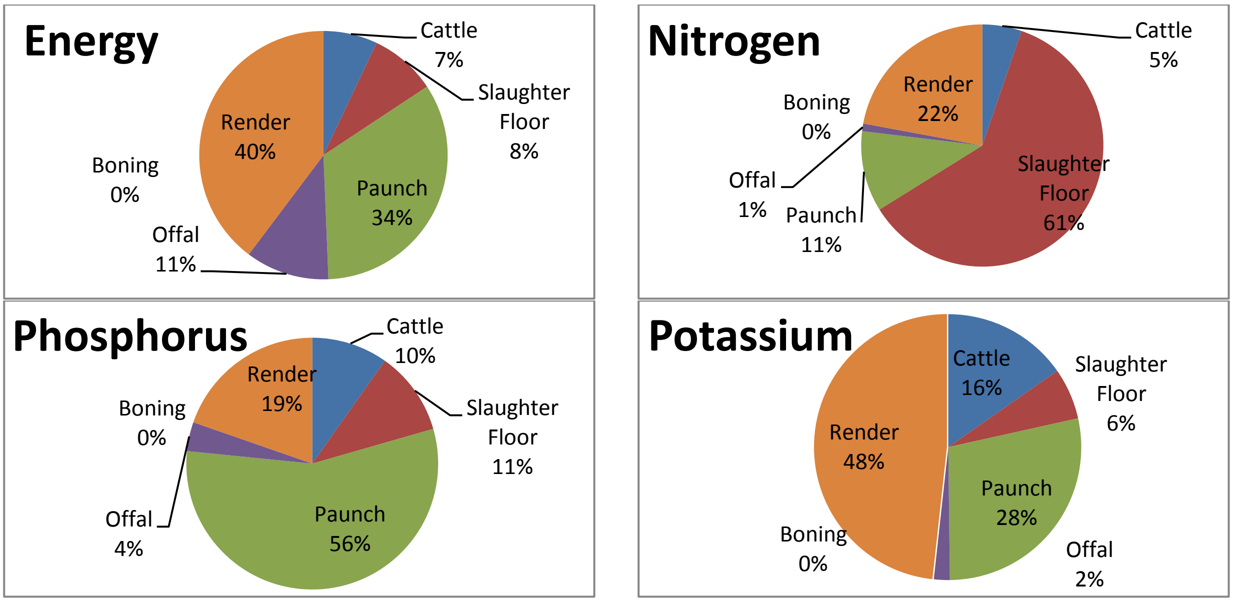

Figure 3: Summary of energy and nutrient loads for each major processing area

DISCUSSION AND CONCLUSIONS

The results indicate there is a substantial opportunity to recover material by treating high-strength material (paunch, rendering, slaughter) through specialised treatment. These higher strength streams can be more effectively treated particularly through anaerobic digestion, which will also release nitrogen, phosphorous, and potassium for subsequent recovery. Given the material is far higher strength than in the bulk stream, precipitative recovery techniques such as struvite precipitation, which has an effective limit of 10 mgP/L in the soluble phase, will be significantly improved (Yuan *et al.*). The high anaerobic biodegradability adds to the economic case for combined anaerobic treatment and nutrient recovery. In the full paper we will get the opportunity to present our recommendations for an alternative treatment train, which would involve solids and liquid phase anaerobic digestion, and allow full energy and nutrient recovery in comparison with existing methods, which carry a substantial carbon and environmental discharge liability. This project was funded by Meat and Livestock Australia and the Australian Meat Processor Corporation.

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