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Review of pre-treatments used in anaerobic digestion and their potential application in high-fat cattle slaughterhouse wastewater

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HIGHLIGHTS

- We review pre-treatment options applicable to wastewater high in fats and oils.
- The unique characteristics of abattoir wastewater are summarised.
- Pre-treatments are evaluated for their potential to improve anaerobic digestion.
- Appropriate pre-treatment technologies are considered on the basis of performance.
- Limitations and future research opportunities in this area are presented.

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ABSTRACT

This paper explores pre-treatment options for the anaerobic digestion (AD) of high-fat cattle slaughterhouse wastewater by assessing and attempting to compare pre-treatment methods used to treat various waste streams. The central focus on cattle slaughterhouse wastewater stems from the problematic nature of high fat, oil and grease (FOG) present in Australian red meat processing (RMP) waste water.

Fully integrated abattoirs such as those operating in Australia typically produce wastewaters that carry high FOG loads of 100–4000+ mg/L. While excessive levels of fat can be inhibitory to the AD process, these fats contain a very high theoretical methane potential of 1014 L CH_4/kg VS when compared with carbohydrates at 370 L CH_4/kg VS and proteins at 740 L CH_4/kg VS. However, due to the hydrophobic and inhibitory nature of fat, oil and grease, accessing this methane potential is difficult. This article serves as a review of the literature in the field of pre-treatment of wastewaters and subsequent anaerobic digestion with the goal of increasing biogas yield, with an emphasis on digestion of wastes high in fat, oil and grease. This review covers mechanical pre-treatments including high-pressure homogenisation, ultrasonication and electrokinetic disintegration, and other forms of pre-treatment including thermal, chemical, thermochemical, and enzymatic hydrolysis, and biochemical emulsification. Biological pre-treatments, also known as pre-hydrolysis and two stage digestion are briefly reviewed. The most significant considerations for selecting a pre-treatment technology are the energy balance and costs. Therefore, this review will also provide a commentary on the advantages and disadvantages of the pre-treatment methods reviewed and conclude by evaluating their relative worth in pre-treating FOG.

Abbreviations: BMP, biomethane potential; COD, chemical oxygen demand; DMDO, dimethyldioxirane; DS, dissolved solids; FOG, fat, oil and grease; GHG, greenhouse gasses; GHz, gigahertz, billion hertz; HPH, high-pressure homogenisation; HRT, hydraulic retention time; KW, kitchen waste; LCFA, long-chain fatty acids; MHz, megahertz, million hertz; MJ, megajoules, million joules; MPa, megapascals; NH_4–N, ammonium as nitrogen; NOx, oxides of nitrogen; pCOD, particulate chemical oxygen demand; PL-250, pancreatic lipase 250; POME, palm oil mill effluent; POMS, peroxymonosulphate; RMP, red meat processing; SBM, stirred ball mill; sCOD, soluble chemical oxygen demand; SS, suspended solids; tCOD, total chemical oxygen demand; tHSCW, tonnes of hot standard carcass weight; TOC, total organic carbon; WWTP, wastewater treatment plant.

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Contents

1. Introduction

Global processing of cattle has intensified consistently over the past 50 years, increasing by 36.29 Mt from 27.69 Mt in 1961 to 63.98 Mt in 2013 [1] (Fig. 1). While production has more than doubled, waste mitigation techniques have lagged behind the ever increasing accumulation of waste.

Processing livestock is an energy and cost intensive process. An environmental sustainability review of the Australian red meat processing (RMP) industry conducted in 2010 revealed that 9.8 kL of water was used to generate a single tonne of hot standard carcass weight (tHSCW) during 2008–2009 and generated 8.7 kL of wastewater. This consumed 4108 MJ of energy from various sources, and committed 11.3 kg of solid waste to landfill, while greenhouse gas (GHG) emissions averaged 554 kg CO_2/tHSCW. Of total energy emissions, 67% were related to electricity use, and 35% of emissions contributed by anaerobic wastewater treatment [2].

The Australian RMP industry is currently working on a range of measures in an effort to reduce carbon pollution and improve energy efficiency through actively seeking renewable sources of energy and water recovery. This has been largely in response to a variety of factors including prolonged drought, water restrictions and rising water costs, rising fuel and energy costs, increased community focus, and GHG emissions. Several knowledge gaps have been identified in which research is needed to reduce the industry's emissions and energy costs [3]. One of the technologies identified as a potential solution reducing emission and energy costs is anaerobic digestion (AD). It has been demonstrated that AD technology can play a major role in waste management and the production of biogas in the abattoirs [4]. The methane produced can be combusted to generate heat and electricity (CHP), or can be refined into renewable natural gas and transport fuels [5]. In addition, AD can be used to manage waste and reduce greenhouse gas emissions, and the digestate may be used or sold as a valuable organic fertilizer substitute or soil amendment [6].

Red meat processors have embraced the uptake of AD systems to treat high-strength wastewater and thereby reduce emissions. In Australia, AD systems typically take the form of low-rate anaerobic lagoons, which are well suited to the vacant land space available with a move to covered anaerobic lagoons to capture methane and reduce GHG emissions [7]. While it has been noted that anaerobic lagoons are not optimised treatment strategies, they are low-capital investments which can affect a large degree of organic degradation and methane generation [8].

The high-strength wastewaters produced in Australian abattoirs tend to contain high levels of fat, oil and grease (FOG) with values ranging between 5 and 4570 mg/L in grab samples [9]. While AD is effective for the degradation of many substrates, FOG present several challenges. Before waste reaches the digester, FOG can adhere to pipe walls and begin the accumulating to form blockages. In the case of covered anaerobic lagoons FOG typically has two fates; accumulation in fatty crust or hydrolysis and digestion to form methane. It has been observed that a large portion of the fatty material floats to the liquid surface along with cellulosics from paunch material to form a fatty crust [10–13]. Fat particles that are hydrolysed to long-chain fatty acids (LCFA) may subsequently adhere to the surface of the sludge microbes. These LCFA form a layer over the microbial surface, producing reversible inhibition of mass-transfer between the microbes and the medium [14].

Australian abattoirs stand to benefit substantially if an appropriate pre-treatment method can be developed to improve the bioavailability and subsequent conversion of FOG to methane. McCabe et al. [15] has shown that biogas production can potentially vary tenfold depending on factors such as lagoon efficiency and operational practices. While no current AD system currently

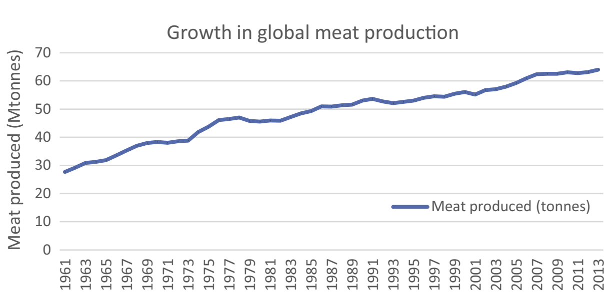

Fig. 1. Growth in global meat production from 1961–2013 [1].