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Biogas from cattle slaughterhouse waste: Energy recovery towards an energy self-sufficient industry in Ireland

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ABSTRACT

This study was carried out to assess the energy recovery potential from organic industrial by-products of a cattle slaughtering facility. There are several processes to convert organic material to energy; the technology of interest in this study was anaerobic digestion, the biological conversion of degradable organic material into methane. The scenario was initially confined to a full scale cattle slaughtering facility processing 3.28% of heads slaughtered in Ireland. The methane potential of dissolved air flotation sludge, paunch, soft offal as well as a mixed waste stream (combination of individual waste streams) was determined through a series of biochemical methane potential assays under mesophilic conditions. The methane potential of the characterised waste streams ranged from 49.5 to 650.9 $mLCH_4\ gVS^{-1}$. The potential energy recovery from the mixed waste stream resulted in the prospective subsidy of 100% of the energy demands of the slaughtering facility as well as the energy demands for the production of the biogas. When investigating the impact of energy recovery from the entire sector the potential energy recovery equated to 1.63% of the final energy demands of the Irish industrial sector. This could potentially increase the RES in Ireland from 7.8% to 8.13% contributing to both RES-E and RES-H.

1. Introduction

1.1. Beef industry in Ireland

Despite unprecedented growth of the Irish economy since the early 1990s, the agri-food sector remains one of Ireland's largest industries as measured by wealth generation (7.7% of GVA), exports (11.5% of total merchandise exports) and employment (9.2% of total employment) [1,2]. A major facet of this sector is Irelands beef industry producing 516,900 tonnes of meat from the slaughtering of over 1.59 million heads of cattle in 2013 [3]. Ireland is the biggest net exporter of beef in the EU and the 5th largest in the world [4]. Export volumes stand at approximately 90% of annual production and contribute 22.3% (2.57% of total merchandise exports) of exports in the agri-food sector in Ireland. High amounts, as much as 45–53% of the live weight of the animal, of organic by-products which are considered to be industrial organic wastes are generated from this industry [5]. As regards the main organic wastes streams, there is blood of the bleeding process, paunch from the removal of the rumen and intestinal content, the intestinal residues from the evisceration processes, fat from the meat trim step as well as the head and the limbs (mostly bone). Moreover, sludge from the wastewater treatment plant of the slaughterhouse is generated. These wastes are characterised by high organic content mainly composed of animal proteins and fats [6–8]. They are strictly managed by legislation, Animal By-Products Regulation (ABPR 1069/2009/EC), in order to prevent the outbreak and spread of diseases such as Bovine Spongiform Encephalopathy and the dangerous human disease Creutzfeld-Jacob [9].

1.2. Treatment of organic waste streams

There are a number of permissible disposal routes under the ABPR with the most common being; material sent for rendering (bones, inedible offal, blood, trimmings etc.) or land spreading (sludge's, paunch, lairage washings etc.). The high organic content of the waste streams generated from the slaughterhouse make them an attractive feedstock for anaerobic digestion (AD) which is considered a suitable treatment method provided approved pre-treatments are applied if required under the ABPR, excluding SRM; material with the highest risk or carrying disease (heads, spinal cord, condemned meat etc.) which is only suitable for

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Nomenclature

ABPR	animal by-products regulation
AD	anaerobic digestion
BMP	biochemical methane potential
C	carbohydrates
CHP	combined heat and power
CSO	central statistics office
DAF	dissolved air flotation
GFC	gross final energy consumption
GVA	gross value added
H	hydrogen
HRT	hydraulic retention time
LCFA	long chain fatty acids
N	nitrogen
NaOH	sodium hydroxide
NREAP	national renewable energy action plan
PA	paunch
RES	renewable energy share
RES-E	renewable energy share-electricity
RES-H	renewable energy share-heat/thermal
SHWM	slaughterhouse waste mixed at annual production ratios
SMY	specific methane yield
SO	soft offal
SRM	specified risk material
TS	total solids
UNFCCC	United Nations framework convention on climate change
VS	volatile solids

incineration or landfilling [7,10–12]. AD has long been considered to be one of the best alternatives for nutrient and energy recovery from organic solid wastes with high protein and fat content [13]. In AD the organic waste is converted to biogas, primarily methane, and a nutrient rich digestate through a series of biochemical processes. The methane produced can be utilised for energy production while the nutrient rich digestate can be employed as a soil conditioner [6]. This alternative treatment method is an effective option, combining material and energy recovery allowing the possibility of an energy self-sufficient industry while incorporating a holistic waste treatment system [6,7,14,15].

1.3. Focus of paper

The focus of this paper is to determine the methane potential of the available organic waste streams, in order to identify the potential energy that could be recovered through the exploitation of AD as an alternative waste treatment within the confines of a full-scale cattle slaughterhouse. The potential energy recovery is assessed in terms of subsidising the process energy of the slaughtering facility and evaluating the degree of energy self-sufficiency that could be achieved. Advancing from the boundaries of a single slaughtering facility, the cattle slaughtering sector in Ireland is also appraised. The contribution of the potential renewable energy generation from the entire sector is assessed in terms of progress towards meeting Irelands 2020 renewable energy targets, RES of 16%, mandated under the Renewable Energy Directive (2009/28/EC) [16].

2. Materials and methods

2.1. Determination of potential methane yield

2.1.1. Slaughterhouse wastes

The sampled slaughterhouse was located in Cork, Ireland and processed approximately 52,000 heads of cattle annually (3.28% of total annual slaughterings in 2013). The slaughtering waste streams considered for this study were paunch (PA), soft offal (SO) (intestinal residues, fat and meat trimmings and some blood) as well as dissolved air flotation sludge (DAF) from the wastewater treatment facility onsite. SRM was not included as per the ABPR regulations while the limbs were not included due to their low biodegradability (primarily made up of bone). As well as treating the three selected waste streams on an individual basis they were mixed together according to their annual production ratios (1:2.55:3.22-PA:DAF:SO), referred to as SHWM from this point on, in order to investigate the implications of treating the three waste streams collectively. Pasteurisation (70 °C for min 1 h) was applied to the SO prior to testing in all cases as per the ABPR for the treatment of category 3 material. The consistency of the wastes in their sampled state did not permit their direct use in accurate BMP assays or composition analysis and thus all samples were mixed and blended thoroughly in order to reduce particle size (<8 mm) and create representative specimens with a uniform particle size. It is important to note that even after the preparation process the offals are still characterised as heterogeneous this reality enforces the need for triplicate testing [6].

2.1.2. Analytical systems

The composition analysis was carried out in terms of basic, organic and elemental characterisation. The basic parameters used for substrate and inoculum description were the Total Solids (TS) and Volatile Solids (VS) content determined in accordance to Method 1684 of the U.S. EPA for Total, Fixed and Volatile Solids in Water, Solids and Biosolids [17]. The organics (VS) within the substrates were further broken down into primary constituents of fats, proteins and carbohydrates. Fats and proteins were determined by an approved laboratory for the microbiological testing of animal by-products in accordance with Commission Regulation 142/2011/EU implementing the ABPR [9,18]. The difference between VS, fats and protein content was designated as carbohydrates. The elemental composition (C, H, N) was determined following the standard operating procedure of a CE440 Elemental Analyser, with O being designated as the difference between VS and the C, H and N content.

2.1.3. Theoretical methane yield

The elemental composition of the substrate (C, H, O) determined from the elemental analysis was used to calculate the gas composition in terms of % CH_4 and CO_2 based upon the stoichiometry of the degradation reaction using the Buswell equation [19];

$$C_cH_hO_o+\left(c-\frac{h}{4}-\frac{o}{2}\right)H_2O\rightarrow\left(\frac{c}{2}+\frac{h}{8}-\frac{o}{4}\right)CH_4+\left(\frac{c}{2}-\frac{h}{8}+\frac{o}{4}\right)CO_2 \tag{1}$$

Eq. (1) in most cases will be optimistic in terms of methane yield since neither non-degradable organics nor energy demand of the bacterial populations is considered [20]. However it can provide a suitable indication as to the biogas composition of the substrates.