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Updraft gasification of poultry litter at farm-scale – A case study

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ABSTRACT

Farm and animal wastes are increasingly being investigated for thermochemical conversion, such as gasification, due to the urgent necessity of finding new waste treatment options. We report on an investigation of the use of a farm-scale, auto-thermal gasification system for the production of a heating gas using poultry litter (PL) as a feedstock. The gasification process was robust and reliable. The PL's ash melting temperature was 639 °C, therefore the reactor temperature was kept around this value. As a result of the low reactor temperature the process performance parameters were low, with a cold gas efficiency (CGE) of 0.26 and a carbon conversion efficiency (CCE) of 0.44. The calorific value of the clean product gas was 3.39 MJ m_N^{-3} (LHV). The tar was collected as an emulsion containing 87 wt.% water and the extracted organic compounds were identified. The residual char exceeds thresholds for Zn and Cu to obtain European biochar certification; however, has potential to be classified as a pyrogenic carbonaceous material (PCM), which resembles a high nutrient biochar.

1. Introduction

The livestock sector is one of the fastest growing subsectors of the agricultural economy driven by growing population and demand for animal protein; however, it faces several challenges in terms of its effect on the natural environment upon which production depends. In particular, it has to adapt to a policy context requiring it to improve its environmental performance and mitigate its impact on climate change.

Poultry was responsible for 33% of the global meat in 2010 (MacLeod et al., 2013) and now accounts for over 80% of the entire world's livestock (FAO, 2015). The poultry sector's growth over the recent decades has moved away from traditional farming practices towards industrialization, geographical concentration and intensification. A direct consequence of these structural changes is that far more waste is produced than can be managed by land disposal. This has given rise to a number of environmental concerns, including bad odours, pathogens, water eutrophication, volatilization of ammonia (NH_3) and emissions of greenhouse gases (De Vries et al., 2012).

At a European Union (EU) level reuse and recycling of wastes are now encouraged over land disposal and legislative restrictions have been introduced. The most significant is the Nitrates Directive (EC, 1991), which aims to protect waters against pollution from nitrates. The choice of waste treatment technologies depends on several factors, e.g. the waste's properties and availability, the desired end products and their economic value. Energy conversion technologies have the advantage of recycling nutrients and recovering energy at the same time. Energy recovery is significant for countries like Ireland. According to Sustainable Energy Ireland (SEI) Ireland imports 86% of its fuels making it the most import dependent country in the EU (SEI, 2015). Furthermore, developments in biomass to energy conversion technologies using e.g. poultry litter (PL), animal slurry and manure, spent mushroom compost and straw would provide a valuable source of employment in rural areas in Ireland. While wet wastes such as cattle manure and pig manure are suitable for bio-chemical conversion, e.g. anaerobic digestion, low moisture wastes such as PL and spent mushroom compost can be subject to thermal treatment, such as combustion, pyrolysis and gasification.

Abbreviations: PL, poultry litter; BM, bedding material; VM, volatile matter; FC, fixed carbon; BD, bulk density; db, dry basis; ar, as received; daf, dry ash free basis; COS, carbonyl sulphides; DL, detection limit; ER, equivalence ratio; CGE, cold gas efficiency; CCE, carbon conversion efficiency; HHV, higher heating value; LHV, lower heating value; MBC, mass balance closure; PCM, pyrogenic carbonaceous material; GC–MS, gas chromatography–mass spectrometry; SEM-EDS, scanning electron microscopy combined with energy dispersive spectroscopy; ICP-OES, inductively coupled plasma optical emission spectrometry; NMR, nuclear magnetic resonance spectroscopy; HPLC, high performance liquid chromatography; SEC, size exclusion chromatography; PAH, polycyclic aromatic hydrocarbons; PCB, polychlorinated biphenyl; TGA, thermogravimetric analysis.

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PL, the waste from broiler production, can vary significantly in its physical and chemical composition depending on its origin and the management practices of the farm. It consists of bedding material (BM), faeces, urine, feathers and waste feed. PL is the most suitable manure feedstock for thermal conversion processes, since its comparably low moisture content reduces the need for pre-treatment (Lynch et al., 2013a). However, some inorganic species, in particular alkali and earth alkali metals ionically bonded with chlorine, cause operational problems, which need to be addressed (Di Gregorio et al., 2014; Font Palma and Martin, 2013a; Lynch et al., 2013b).

Recently, the European Commission (EC) decided to allow PL to be used as a fuel for on-farm combustion under existing animal by-product regulations (Commission Regulations (EU) No. 592/2014). On-farm application offers several advantages for farmers, mainly to have the benefit of handling their own waste and to produce heat for the poultry sheds in winter and a natural fertilizer without having to pay expensive waste disposal and transportation costs. Furthermore, the excess product gas can be easily distributed to other sites in the vicinity. Combustion of PL is already successfully being applied on farm-scale (BHSL, 2011), using the energy for heating the poultry sheds and the residual ash in the PK fertilising industry.

Gasification is an advanced thermochemical treatment technology which transforms the solid manure biomass into a gaseous energy carrier called "syngas" or "product gas" under sub stoichiometric oxygen conditions (Arena, 2012). This means that the oxygen supply is lower than that required for complete combustion. Gasification offers some advantages over conventional combustion as highlighted by Basu (2010a); the gas volume is less, which requires smaller equipment, the gas can be easily transported and gas handling is easier compared to a solid biomass. In addition, the gas could be distributed to individual houses or units to be used as a fuel for cooking or heating. Gasification produces less NO_x and SO_x emissions due to the lower oxygen supply and operating temperature; however undesired gaseous species, which occur in a reducing environment, might be formed, such as H_2S, HCl, carbonyl sulphides (COS), HCN, and NH_3. Depending on the final application of the product gas, gas cleaning units are required. In particular, for gas turbines and engines there are defined limits for contaminants, including tar, dust, alkalis, heavy metals, H_2S and HCl. For large scale operations the installation of a product gas cleaning unit is economically feasible. Nevertheless, Lee et al. (2013) demonstrated the possibility of generating electricity from biomass using a trailer-scale integrated system for distributed energy and rural applications. For their engine application they installed a cyclone, cooling tower and two filters to clean the gas of dust particles and tars.

Scientific literature on PL gasification is still fairly limited since PL is an unconventional fuel to gasify owing to its high ash content. In fact, the use of PL for thermal treatment might have to be seen primarily as a waste treatment option, while producing energy as a useful side product, rather than aiming to achieve high process performance. The critical focus of scientific investigations has been to understand and mitigate operational difficulties related to ash during fluidized bed gasification (Di Gregorio et al., 2014; Font Palma and Martin, 2013a). Priyadarsan et al. (2004) performed a study on updraft gasification of poultry manure and concluded that a high alkali content in the feedstock leads to ash agglomeration in the fuel bed. Font Palma and Martin (2013b) used chemical equilibrium modelling to design compact reactors to suit on-site applications for heat and power generation from PL. Their optimised configuration achieved modelled electrical efficiencies of between 26% and 33.5%.

Selecting the right type of gasifier depends on the capital, operating and maintenance costs, the size, simplicity and feedstock properties and pre-treatment (drying, separation, size, reduction, pelletisation). Updraft gasifiers are the oldest and simplest design. They are also known as counter current gasifiers, since the oxidizing agent travels upwards and the bed of fuel moves down. They are considered suitable for gasifying feedstocks with relatively high moisture and ash content (50 wt.% and 15 wt.% respectively), have a high thermal efficiency due to low exit gas temperature, and have a low ash carryover due to the filtering effect of the fuel bed (McKendry, 2002; Priyadarsan et al., 2004). The simple reactor design and low investment make this type of technology very attractive for on-farm application; however, the technology has several disadvantages which have to be addressed before application, such as poor temperature control and tar formation.

There are relatively few reports in the scientific literature of the operation of on-farm gasification of PL. This paper proposes a critical analysis of updraft gasification of PL at farm-scale. The aims were to evaluate the process performance of an existing updraft gasification system, to characterise the side products and give suggestions for their practical use.

2. Materials and methods

2.1. Gasification process and operation

A schematic of the on-farm updraft gasification system is presented in Fig. 1. The fixed bed reactor was cylindrical in shape with an average feed rate of 40 kg h^{-1}. The feedstock was transferred from a hopper to the top of the reactor by means of a motorised screw feeder. The reactor was filled to the top with PL, which was continuously rotated downwards at approximately 5 rpm using steel impellers. Two induced draft fans located downstream from the gasifier pulled the gasification medium air from the bottom of the reactor through the gasification system generating the updraft, which also resulted in a slight pressure drop. The speed of the fans controlled the air flow rate and air intake to maintain a bed temperature between 580 and 680 °C. Two thermocouples were placed inside the reaction zone of the reactor to measure the temperature. The gasifier was preheated with propane gas which was initially maintained as the feedstock was added until auto-thermal conditions were achieved. Tar and water condensed on the cold surfaces of metal packing in two water cooled scrubber units and were collected in a storage tank. The gas entered the first scrubber at around 85 °C and exited it around 50 °C; the gas exited the second scrubber at around 32 °C. The product gas passed through an additional air cooled heat exchanger with the aim of lowering the moisture content in the gas before flaring in a gas burner. A Testo 350 XL was used to measure the flow rate of the cooled product gas, being 28.8 $Nm^3\,h^{-1}$ at 12.3 °C. The residual unconverted solid char passed through a grate at the base of the gasifier and was augered into a sealed collection drum. The flow rates of the char and the tar/water emulsion were determined several times by measuring the mass output during a time period of 30 min. A more detailed description of the gasifier and the process can be found in Joseph et al. (2012). The gasifier operated for 14 h on each of three consecutive days and >560 kg of litter was gasified.

2.2. Feedstock and product characterisation

Wood shavings from Sitka spruce trees were used as a BM prior to the stocking of birds on the broiler farm. The broiler chickens were fed a conventional diet suitable to their age. In the first 3 weeks the chickens were fed so-called "starter feed", between 3 and 6 weeks they were fed "grower feed" and between 6 and 8 weeks they were fed "fattener/finisher feed". The poultry sheds

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