The influence of the pig manure separation system on the energy production potentials

R. Wnetrzak [a], W. Kwapinski [a], K. Peters [b], S.G. Sommer [c], L.S. Jensen [b], J.J. Leahy [a,*]

[a] Carbolea Research Group, Department of Chemical and Environmental Science, University of Limerick, Limerick, Ireland
[b] Department of Agriculture and Ecology, Faculty of Science, University of Copenhagen, Thorvaldsensvej 40, 1871 Frederiksberg, Denmark
[c] Institute of Chemical Engineering, Biotechnology and Environmental Engineering, University of Southern Denmark, Denmark

HIGHLIGHTS

- Energy recovery from pig manure as an opportunity for waste utilisation & profit.
- Pre-treatment of manure influence composition of the separated solid fraction.
- Pre-treatments influence the properties of the products of pyrolysis.
- Energy recovery via combustion and pyrolysis process.

ARTICLE INFO

ABSTRACT

Energy recovery from pig manure offers an opportunity for waste utilisation and financial benefit. Samples of the solid fraction of separated pig manure and samples which had undergone chemical or biological pretreatment prior to separation were pyrolysed. A beech wood sample was pyrolysed for comparison. The chemically pre-treated and anaerobically digested materials had similar properties and showed similar behaviour during thermogravimetric analysis. However, the energy content of the gas arising from pyrolysis in a batch reactor at 600 °C comprises about 30% of the original energy of the feedstock in the case of the anaerobically digested materials and double that of the chemically pre-treated material. Therefore, the overall energy balance showed a loss of 595.9 MJ/t for the pyrolysis of the chemically pre-treated manure, while very small positive values of 351.7 MJ/t, 817.3 MJ/t and a significant value of 8935 MJ/t were found for anaerobically digested sample, un-pretreated solid and for wood, respectively.

1. Introduction

The intensification of livestock production systems in Europe is increasing the risk of environmental impacts from food production because in many cases the organic waste nutrients exceed that required for crop production. The total amounts of nitrogen (N), phosphorus (P) and potassium (K) in livestock manures produced annually are larger than the world production of synthetic N, P and K fertilisers (Steinfeld et al., 2006). Regional variations are large, with most livestock manures being produced in Europe, China, India and parts of North America and Latin America (Steinfeld et al., 2006). Jutland in Denmark, South-East of the Netherlands, Belgium, Central Poland, Catalonia and Murcia in Spain, Lombardy in Italy and Brittany in France are the regions of the highest pig concentrations in EU. In 2009, 153,226,384 pigs (FAOSTAT, 2009) produced 148.59 M tons of pig slurry and 5.307 M tons of pig deep litter in Europe. If used appropriately, manure can displace significant amounts of mineral fertilisers in areas with intensive livestock production, with the additional benefit of contributing to the maintenance of soil organic C stocks (Schröder, 2005). However, inappropriate management causes environmental problems such as surface water eutrophication, ground water pollution, greenhouse gas emissions during storage and/or application (Prapaspongsa et al., 2010). Effective management & recycling of the organic matter and plant nutrients of animal manures can mitigate the environmental impacts, contribute to crop fertilisation, and reduce the requirement for mineral N, P, K and micronutrients. In the areas of extensive livestock production new improved, technologies for conversion of the manures to less harmful and more reusable products are therefore urgently needed.

Biowaste can be converted into potentially valuable energy products via thermal (combustion, pyrolysis, gasification and liquefaction) and biochemical/biological process. The main factors that influence the choice of energy conversion technology are the feedstock properties (McKendry, 2002a), products end-use requirements (Oasmaa et al., 2005), economic issues and environmental standards

---

(Brown et al., 2009). The major factor dictating the energy conversion is the dry matter content of the feedstock, which in the case of raw pig manure is less than 8%. The application of thermal conversion technology requires relatively dry feedstock. Hence, separation is necessary to divide manure into a high dry matter (DM) and nutrient-rich fraction as well as a nutrient-poor liquid fraction with high water content. Separation technologies can be classified as either forced where the slurry is condensed by mechanical means such as screw press or centrifuge or naturally separated by sedimentation (Hjorth et al., 2010).

Different technologies for slurry separation partition nutrients and particles into the solid fraction with varying efficiencies (Hjorth et al., 2010), so that solid fractions with varying characteristics are produced (Jørgensen and Jensen, 2009). The separation efficiency of these technologies depend on the slurry composition and particle size of the solid components. The separation efficiency can be augmented by pretreating the slurry using chemical techniques such as flocculation, coagulation or precipitation. Pre-treatment can affect both, the relative amounts of solid and liquid as well as their composition in terms of protein, fats, cellulose, hemicellulose and mineral content.

The solid fraction of separated pig manure can be suitable for energy production with the recoverable energy yields varying with the calorific value, moisture and ash content as well as proportions of fixed carbon and volatiles (McKendry, 2002a). The solid fraction of separated slurry is generally suitable for biogas production; however gas yields vary according to both the pre-treatment methods and separation technologies, arising from variations in the content of carbohydrates, proteins and fats (Weiland, 2010). Thus the content of volatile solids (VS) is often used as an indicator for the degradable amount of carbon (C) for biogas production. The gas produced from anaerobic digestion process (AD) has an energy content of about 20–40% of the lower heating value of the feedstock and the overall conversion efficiency from biomass to electricity is about 10–16% (McKendry, 2002b).

In addition to high calorific value methane, the AD process produces a digestive containing poorly degradable solid residue. This digestive is potentially harmful for the environment if it contains significant concentrations of hazardous heavy metal ions (e.g. from supplementary waste feedstocks) and pathogens and its disposal may thus become a problem. Even though, the development of sludge pre-treatment is on-going to increase biodegradability (Kim et al., 2003) the application of thermochemical technologies, such as pyrolysis, gasification or combustion is also an option for converting both raw or digested pig manure solids into bioenergy (Shen and Zhang, 2003).

In this study, pyrolysis process was investigated as a technique for recovering energy from different mechanically separated pig manures. Pyrolysis is a thermochemical process wherein biomass is heated in the absence of oxygen. Unlike combustion the outputs from pyrolysis include three potential energy carriers, a bio-liquid, a bio-gas, and a residual solid char (BC) (termed biochar when further applied to soil).

There are two types of pyrolysis: fast and slow. The difference in the feedstock higher heating value (HHV), its moisture, ash and volatile matter contents dictates the type of pyrolysis used as well as affecting the yield, chemical properties and energy value of the products formed (Kwapinski et al., 2010; Cao and Harris, 2010). Pyrolysis using a fixed bed reactor allows conversion of biomass with variable particle size (Melligan et al., 2011) and is usually called 'slow' pyrolysis. Pig manure contains a significant amount of non degradable mineral matter which remains in the char component at the temperatures found in conventional pyrolysis processes (up to 650 °C). The bio-gas from pyrolysis of pig manure is known to contain H_2, CH_4 and other high calorific value hydrocarbons such as C_2H_6, C_2H_4 (Ro et al., 2010).

The aim of this study was to investigate the effect of separation technologies on the slow pyrolysis of the recovered solid fractions. The analysis includes investigation of (i) the DM and energy contents of the pig manure solid fractions; (ii) nature of feedstock on the pyrolysis behaviour using thermogravimetric analysis (TGA) (iii) nature of feedstock on the yield and energy contents of the pyrolysis products obtained as well as (iv) to compare energy production potentials via pyrolysis and combustion processes of the solid fractions from three differently pretreated and separated pig slurries compared to wood.

2. Methods

2.1. Analytical methods

During 2007, 42 samples of solid fractions from separated pig manure slurries were collected from slurry separators, operating at intensive livestock farms in Denmark. The chemical and biochemical composition of the biomass solid fractions as well as products of thermal conversion were analysed and the methods are described below. More detailed descriptions of sampling and analytical procedures as well as composting, N mineralization and methane production of raw, separated and AD pig manure samples can be found elsewhere (Peters, 2010). From the 42 original samples, a subset was selected for pyrolysis experiments and analyses of output gas, bio-liquid and char. The subset comprised of 1 sample each of decanter centrifuged anaerobically digested slurry, chemically pre-treated mechanically separated slurry and mechanically separated slurry.

DM content, N and P concentrations, and biochemical characterization of the composition of the solids was described by (Jørgensen and Jensen, 2009). Surface area of the BC samples was determined by multipoint BET using a Gemini 2375 V5.01 surface area analyser (Micromeritics Instrument Co., USA). Moisture content of feedstock and char samples was determined according to – ICS 75.160.10, DD CEN/TS 14774-3:2004: solid biofuels – methods for the determination of moisture content – oven dry method. The moisture content of the pyrolysis oil samples was determined by Karl-Fischer titration (Mettler Toledo DL 31) using Hydranal Composite 5 with Methanol–Chloroform (3:1) used as a solvent (acc. ASTM D95). Measurements of C, H, N contents were carried out by means of an Elemental Vario el Cube Analyzer. The composition of C, H, N were expressed on a dry matter basis. The higher heating value of the bio-oil (HHV) was calculated based on the C, H, and N contents from the elemental analyses according to the following equation (Friedl et al., 2005):

$$HHV = 3.55C^2 - 232C - 2230H + 51.2C \cdot H + 131N + 20,600.$$
(1)

The oxygen content of the feedstock was obtained by subtracting the percentages of C, H, N, and ash from 100%. The HHV of feedstock and char was determined using a Parr 6200 bomb calorimeter according to SIN 6206-0712-2394 standard. Benzoic acid was used as a standard. Gas composition was analysed using an Agilent micro-GC 3000. The gas HHV was calculated according to the equation (Basu, 2010):

$$HHV = (39.82CH_4 + 12.63CO + 12.74H_2 + 63.41C_2H_4 \\ + 70.29C_2H_6 + 58.26C_2H_2)/100.$$
(2)

The NH_3 concentration in the gas samples was measured using a Kitagawa AP-1 gas detector tube system and a Gastec No. 3H ammonia detector tube with a measuring range 0.2–32%. The pH of the bio-oil was determined at 25 °C using an Orion 420 pH metre. Ash content of feedstock and biochar was analysed according to ICS